K2

Dennis Stello

(Sanjib Sharma, Daniel Huber)

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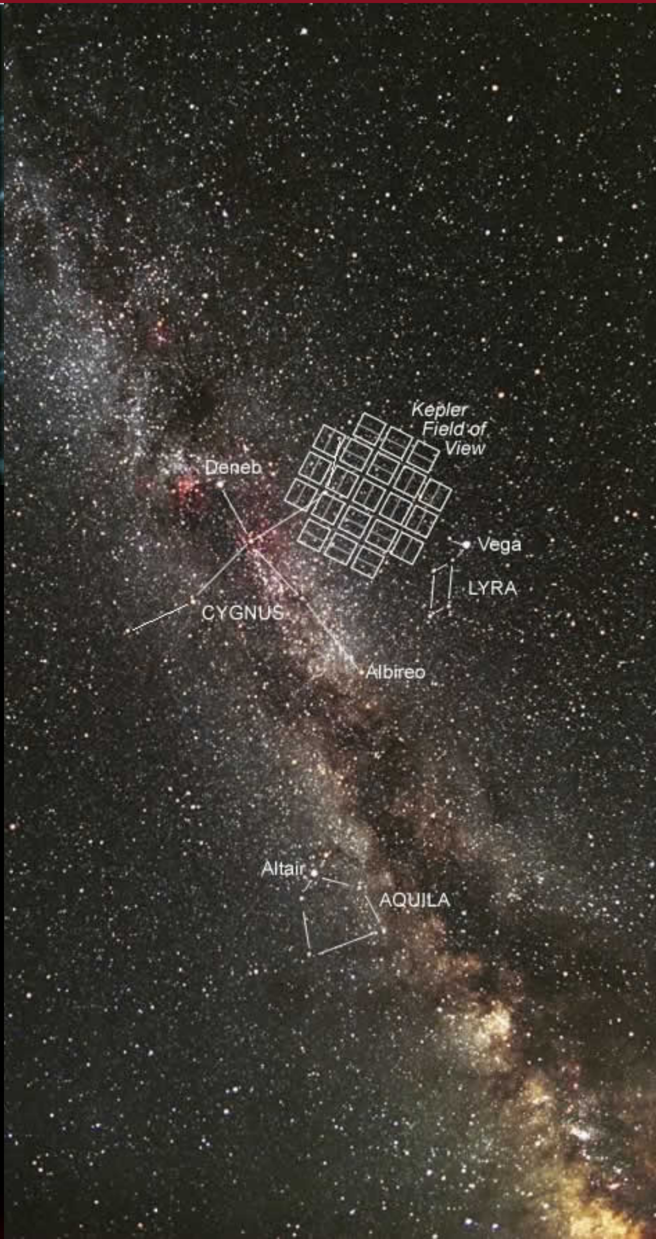
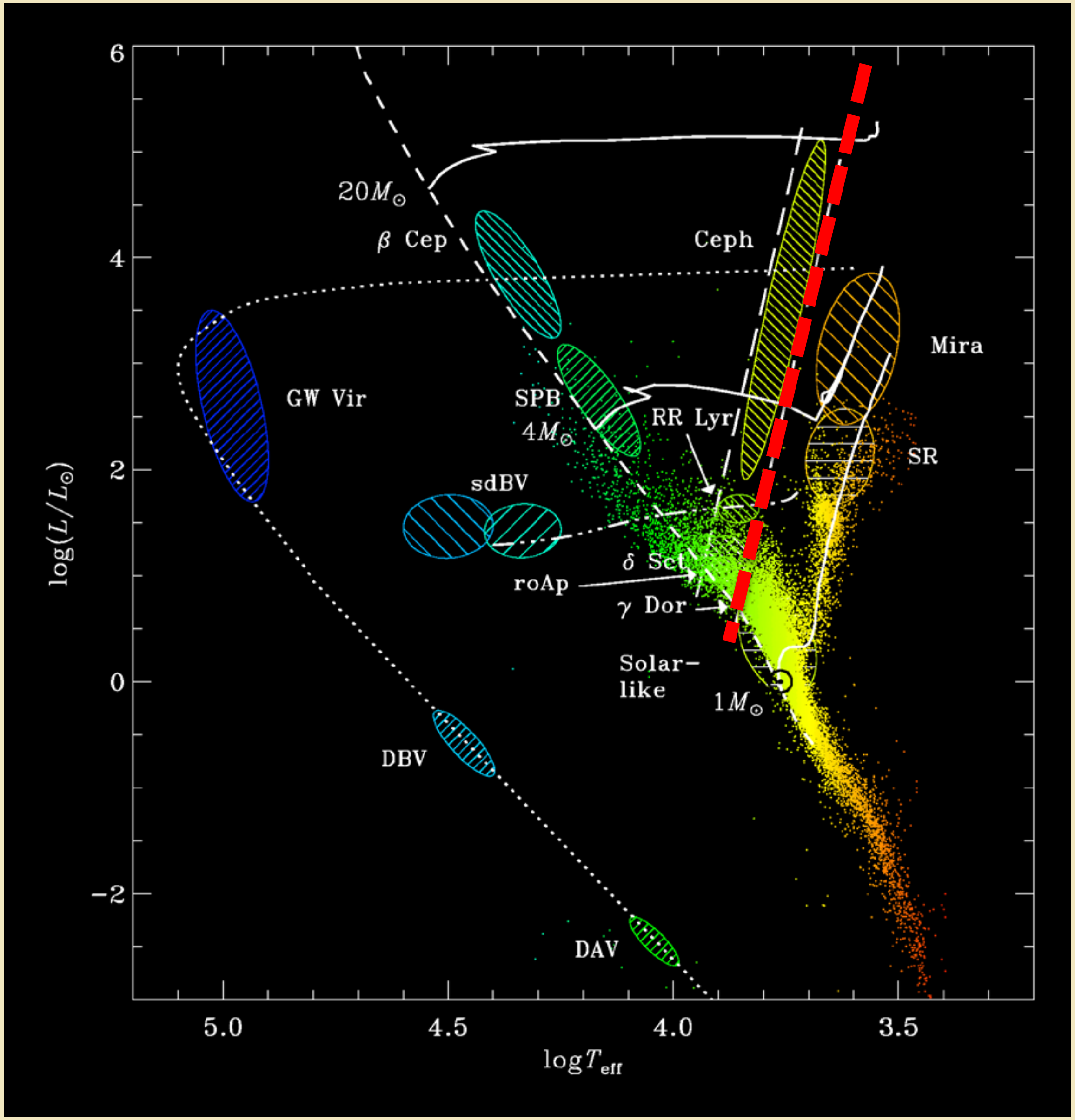
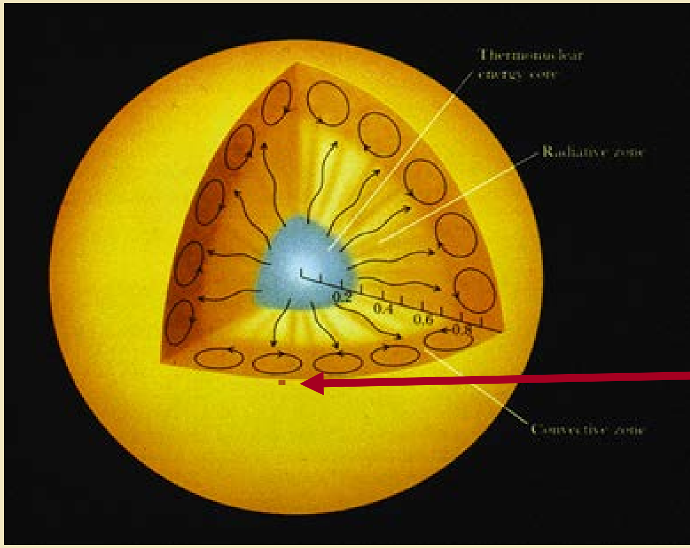
The Kepler mission 2009-2013

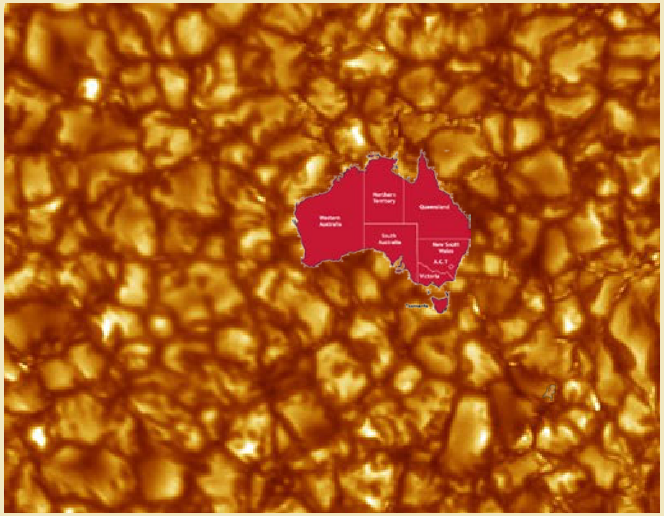


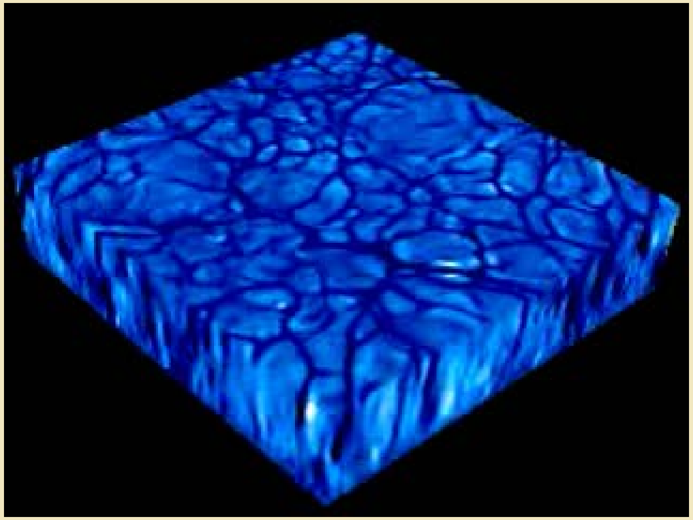
Asteroseismology

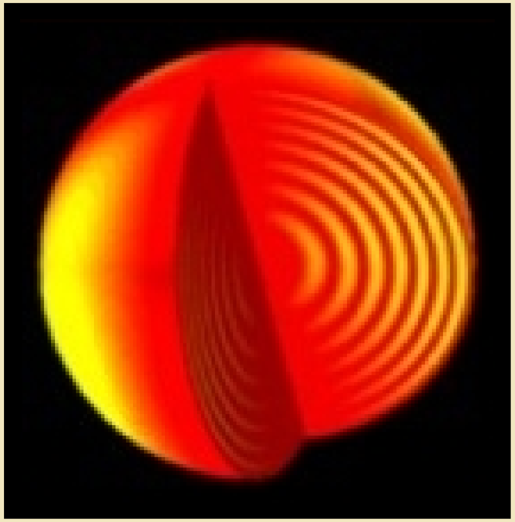


Asteroseismology



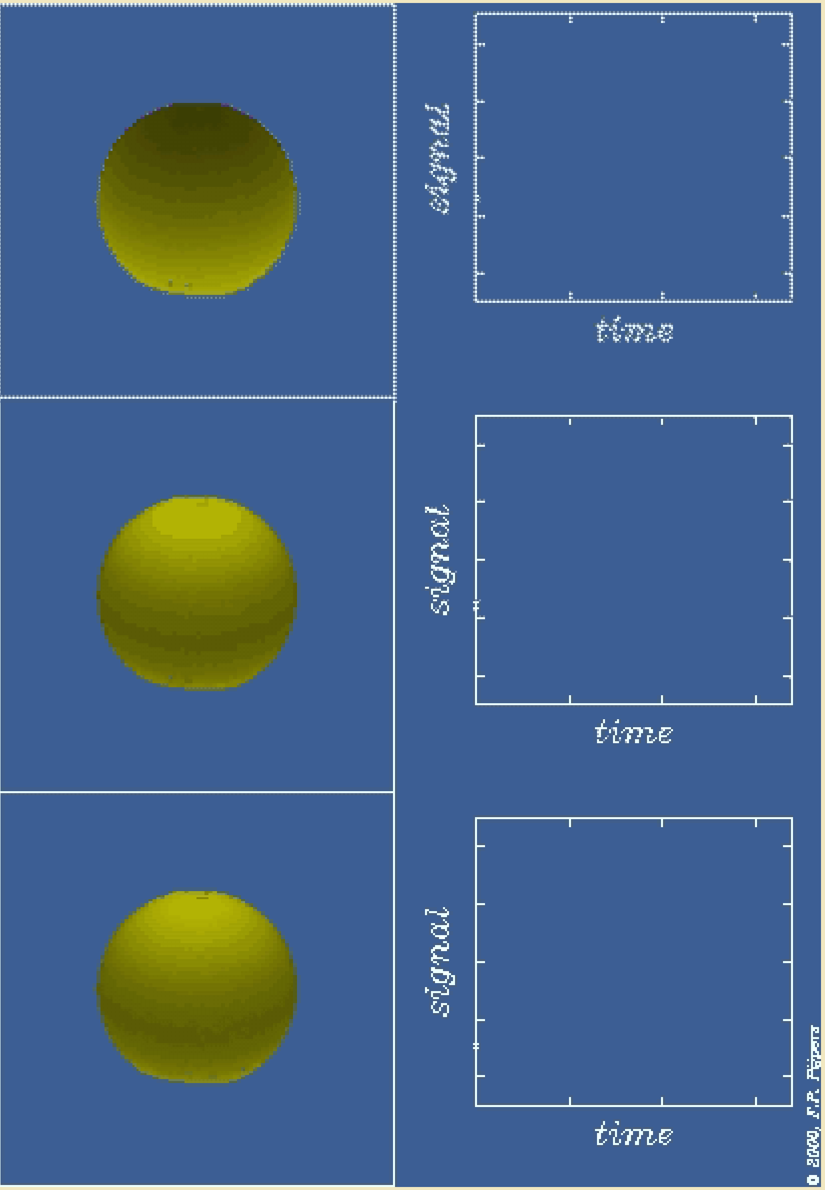


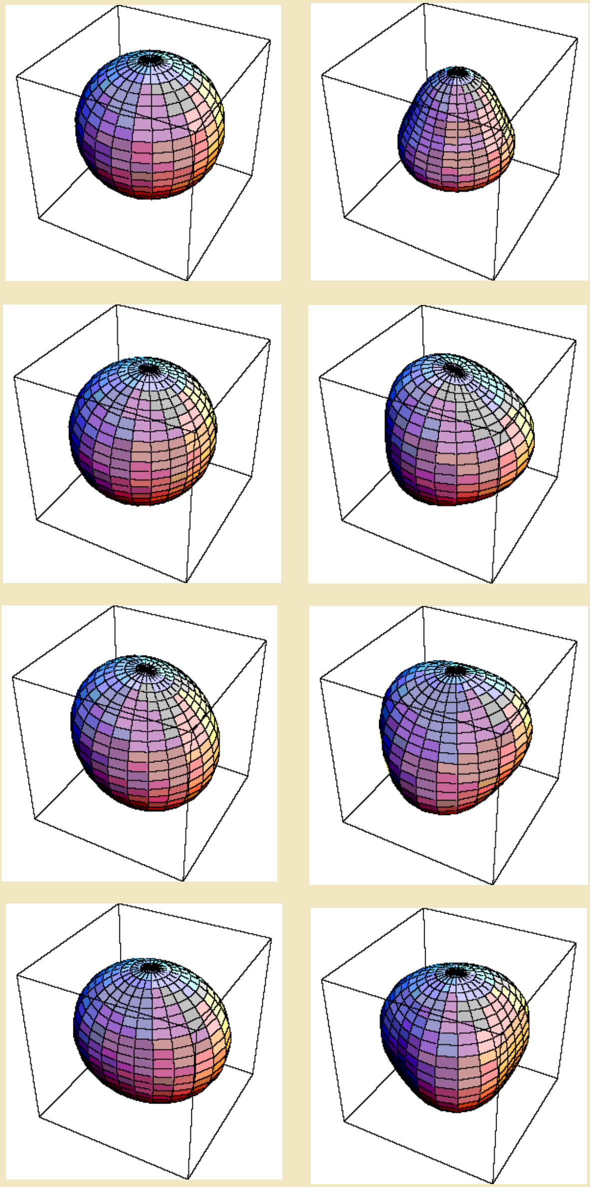




Standing sound waves

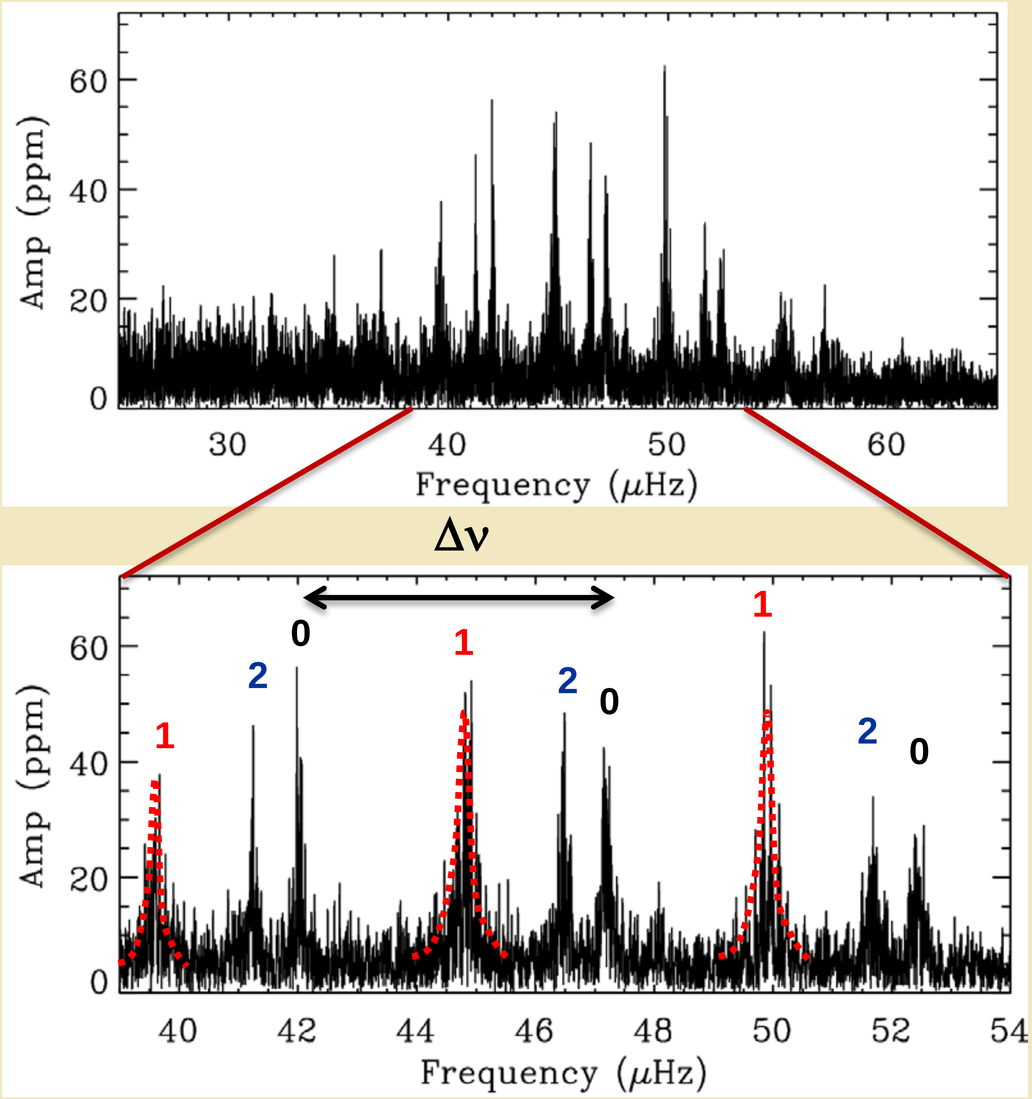
Observing standing waves





The power spectrum

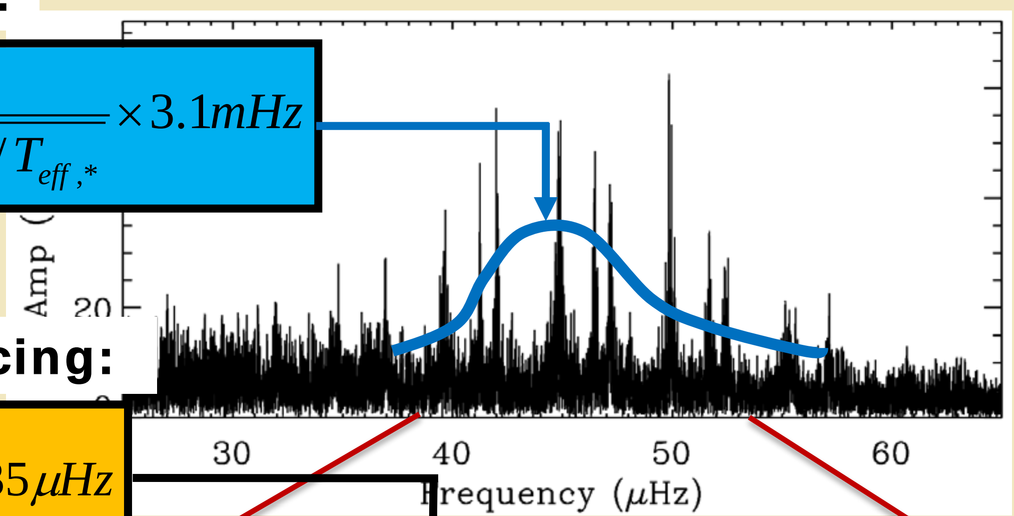
Fourier transform of light curve



Ensemble seismology: M, R, L

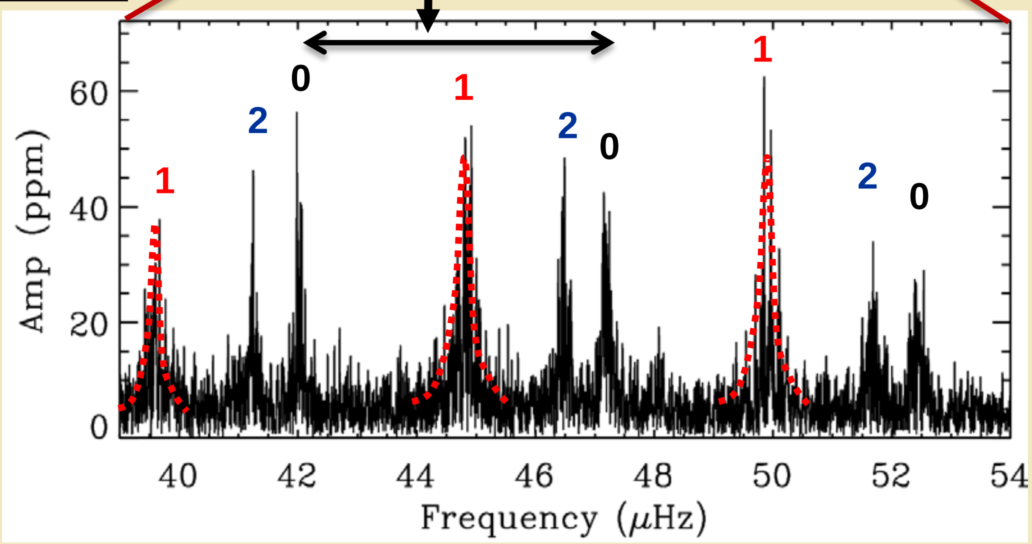
Power location:

$$\nu_{max} \cong \frac{M/M_*}{(R/R_*)^2\sqrt{T_{eff}/T_{eff,*}}} \times 3.1mHz$$



Frequency spacing:

$$\Delta\nu \cong \frac{(M/M_*)^{1/2}}{(R/R_*)^{3/2}} \times 135\mu Hz$$



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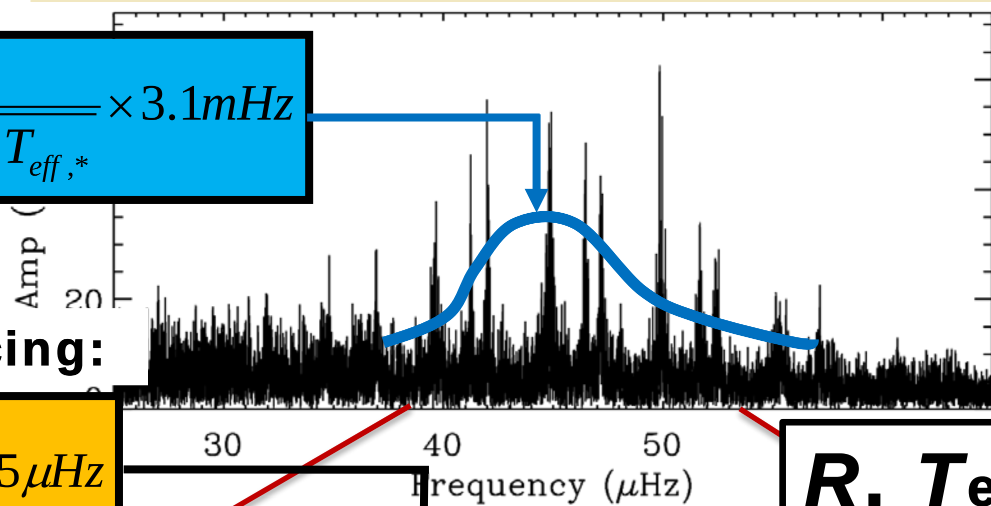


Frequency spacing:

$$\Delta\nu \cong \frac{(M/M_*)^{1/2}}{(R/R_*)^{3/2}}\times 135\mu Hz$$

Δν

distance

R, Teff → L

$$\frac{M}{M_\odot} \simeq \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)^3 \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-4} \left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{3/2}$$

$$\frac{R}{R_\odot} \simeq \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right) \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-2} \left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{1/2}$$

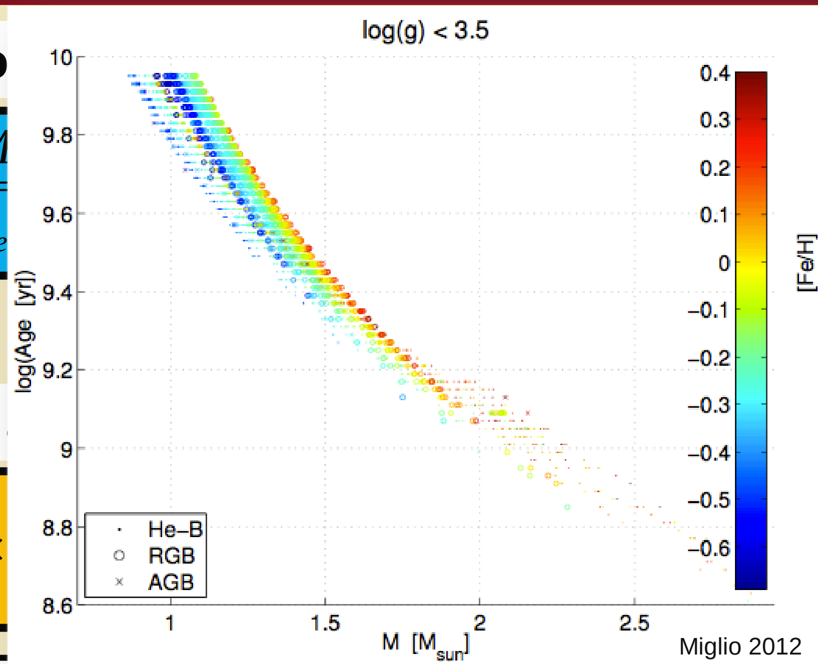
Ensemble seismology: M, R, L

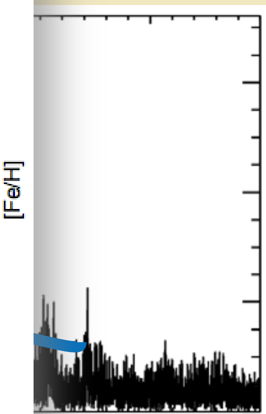
Power locatio

$$\nu_{max} \cong \frac{M / M}{(R / R_*)^2 \sqrt{T_e}}$$

Frequency sp

$$\Delta\nu \cong \frac{(M / M_*)^{1/2}}{(R / R_*)^{3/2}} \times$$





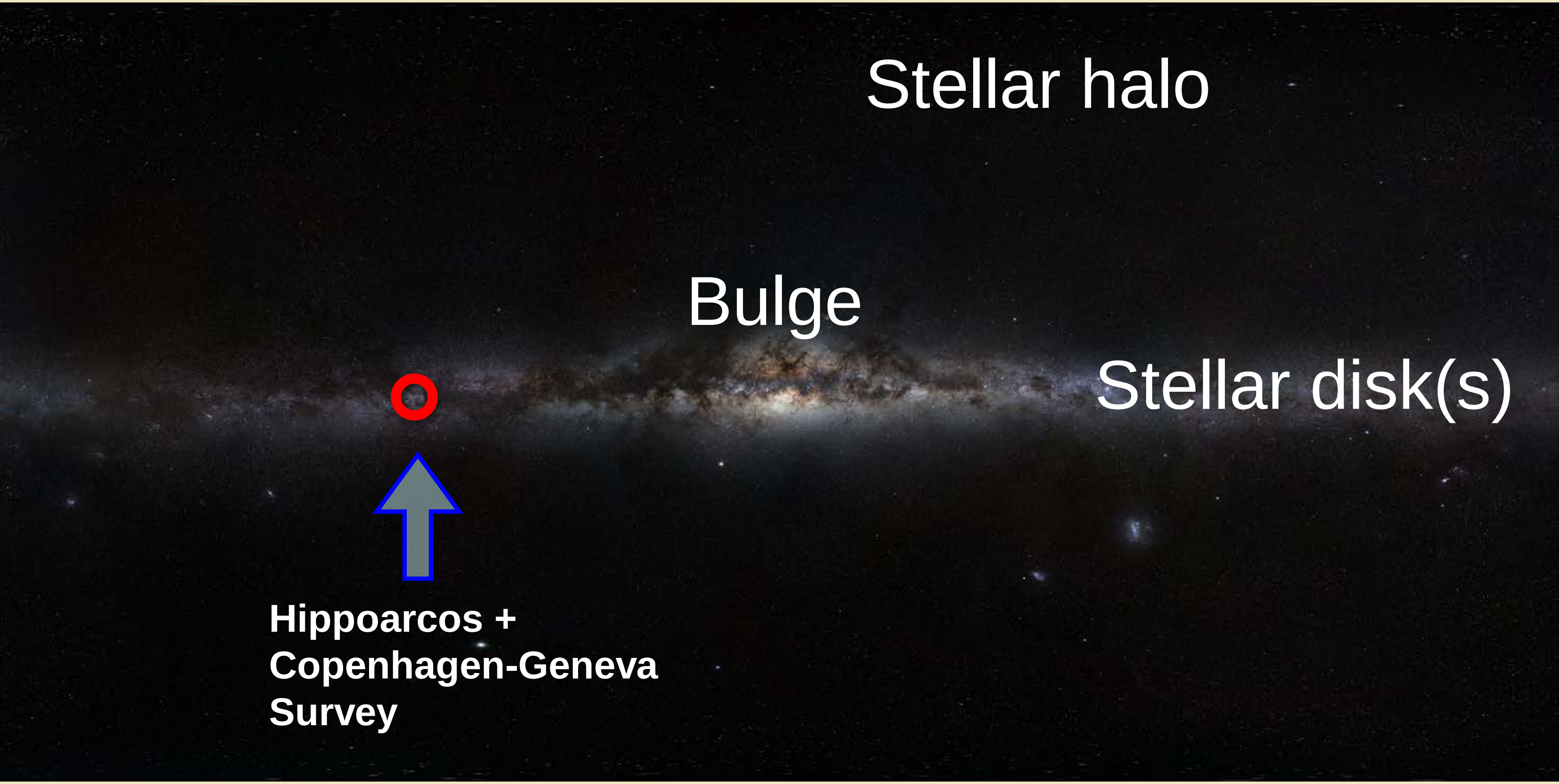
distance

R*, *T*eff → *L

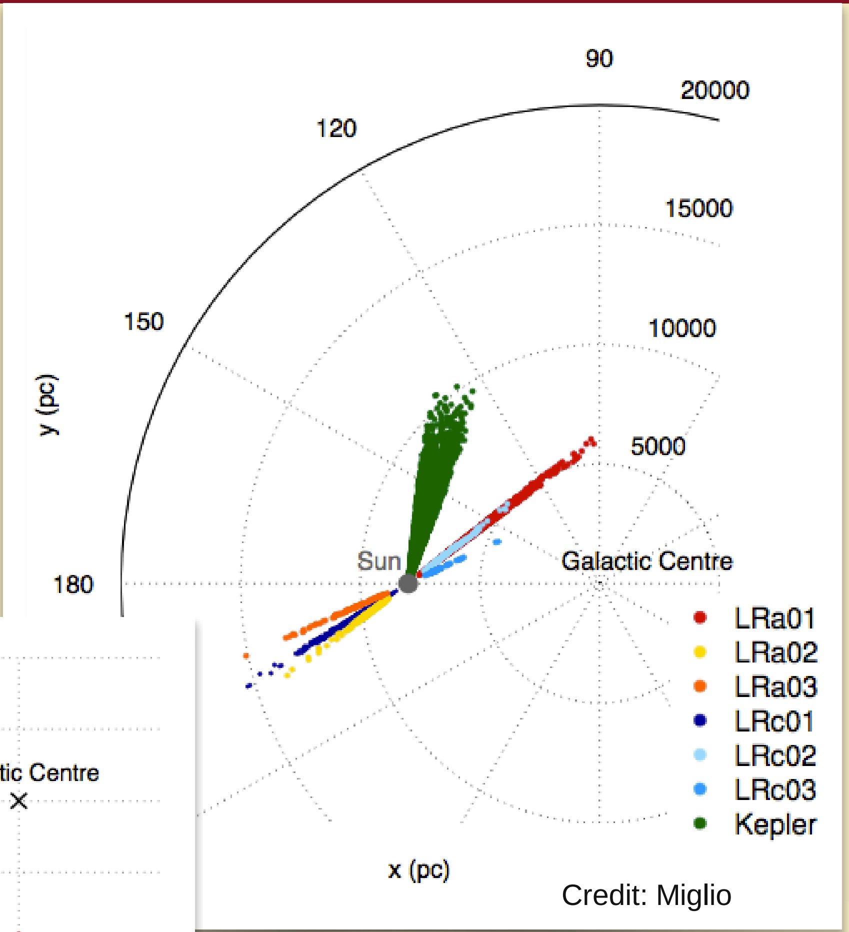
$$\frac{M}{M_\odot} \simeq \left(\frac{\nu_{max}}{\nu_{max,\odot}}\right)^3 \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-4} \left(\frac{T_{eff}}{T_{eff,\odot}}\right)^{3/2}$$

$$\frac{R}{R_\odot} \simeq \left(\frac{\nu_{max}}{\nu_{max,\odot}}\right) \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-2} \left(\frac{T_{eff}}{T_{eff,\odot}}\right)^{1/2}$$

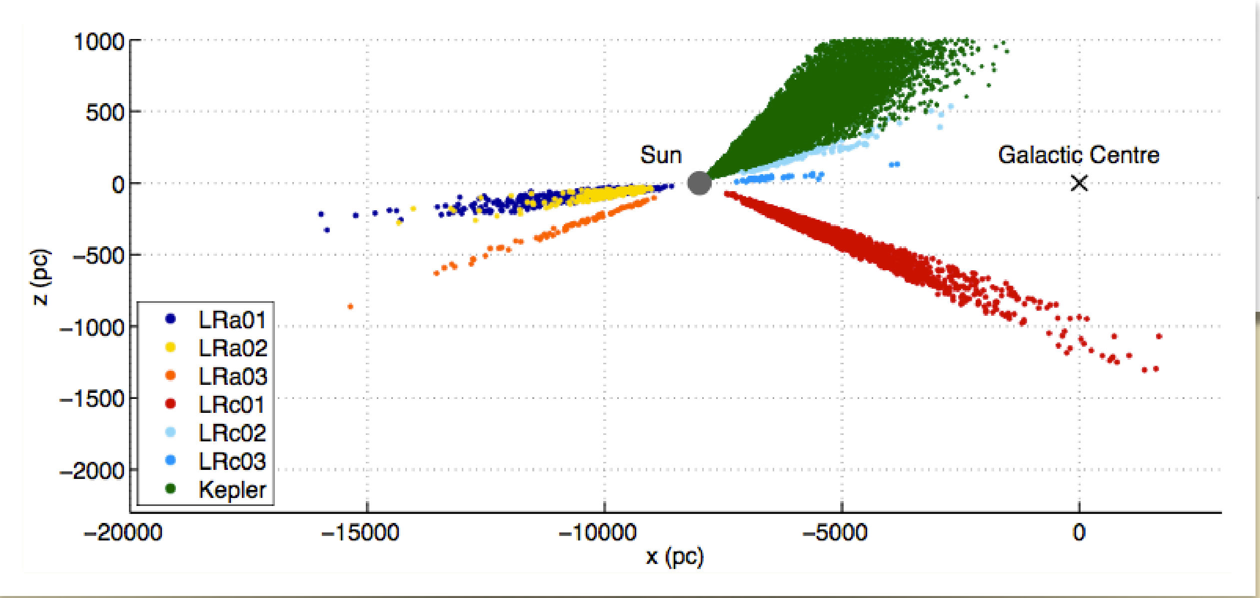
Our Galaxy


Stellar halo
Bulge
Stellar disk(s)
Hippoarcos +
Copenhagen-Geneva
Survey

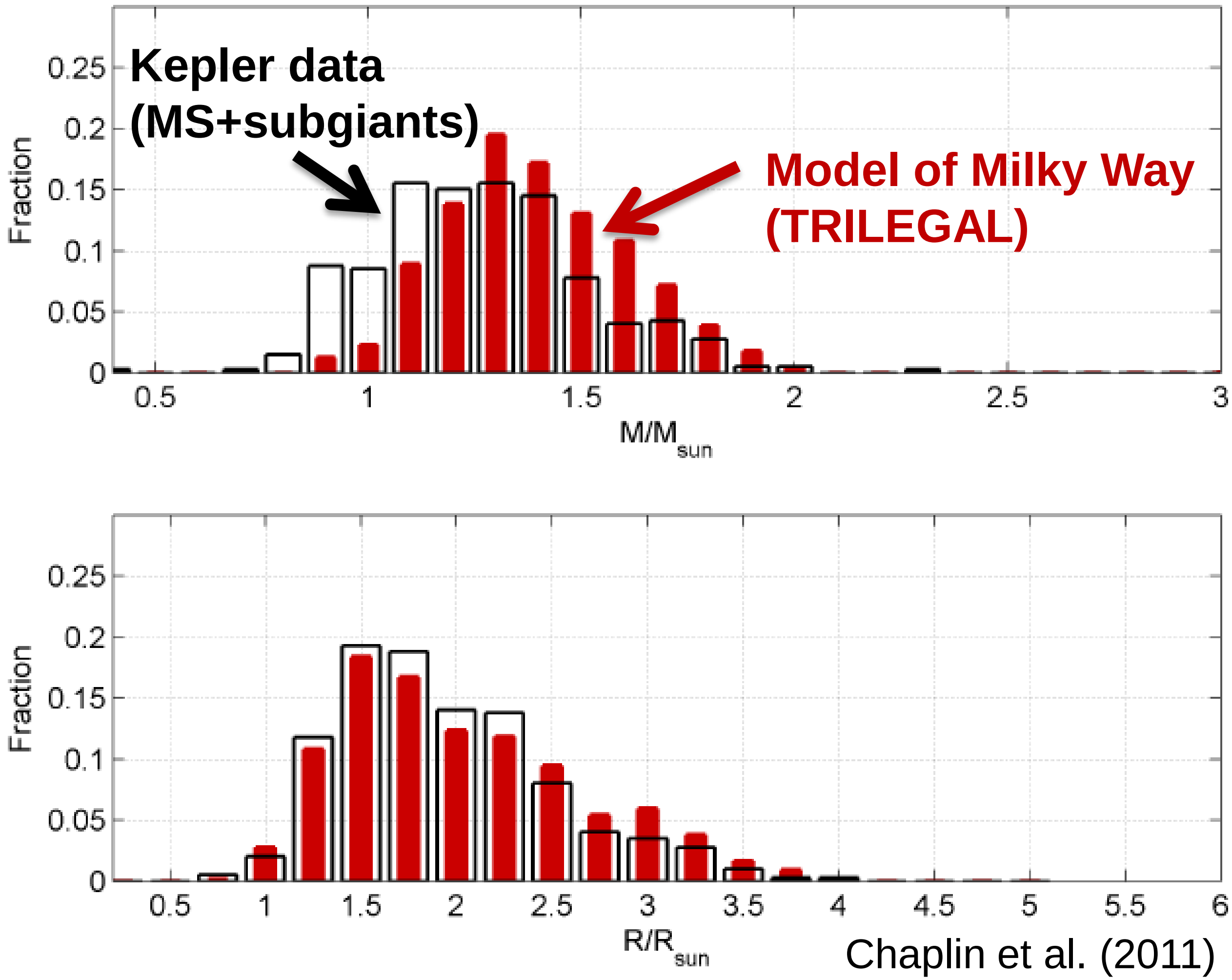
Early results from Kepler and CoRoT



Credit: Miglio



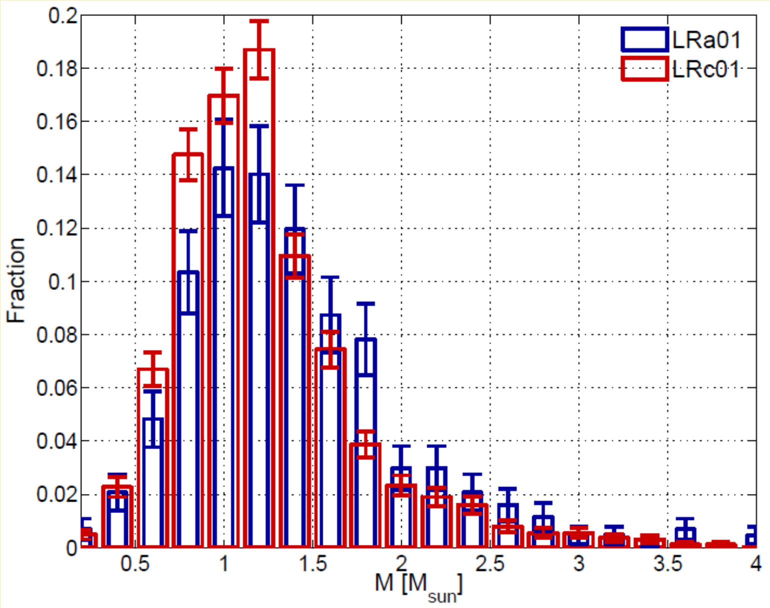
Early results from Kepler and CoRoT

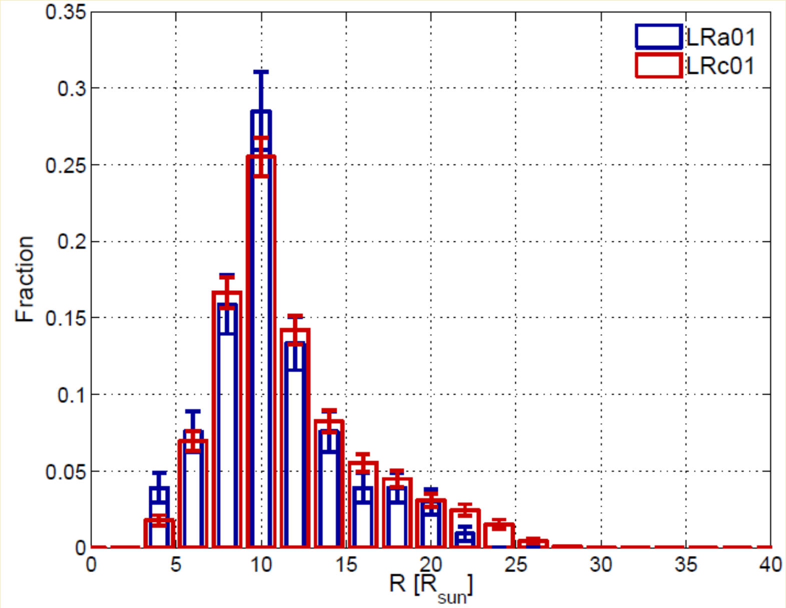


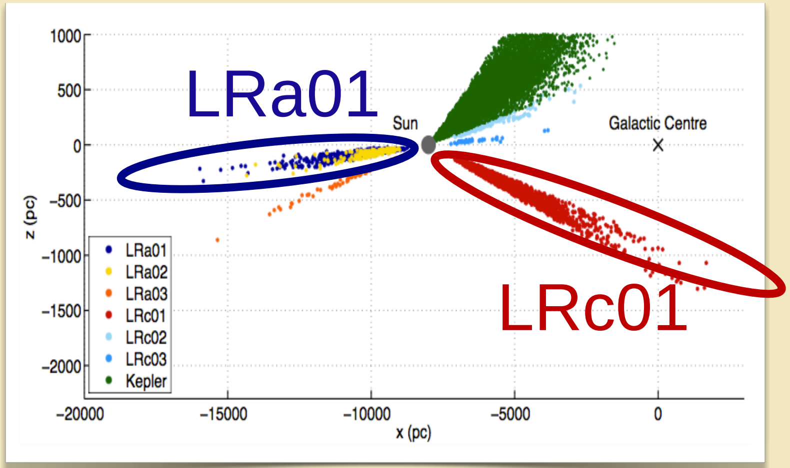
Chaplin et al. (2011)

Early results from Kepler and CoRoT

Observed Red giant stars

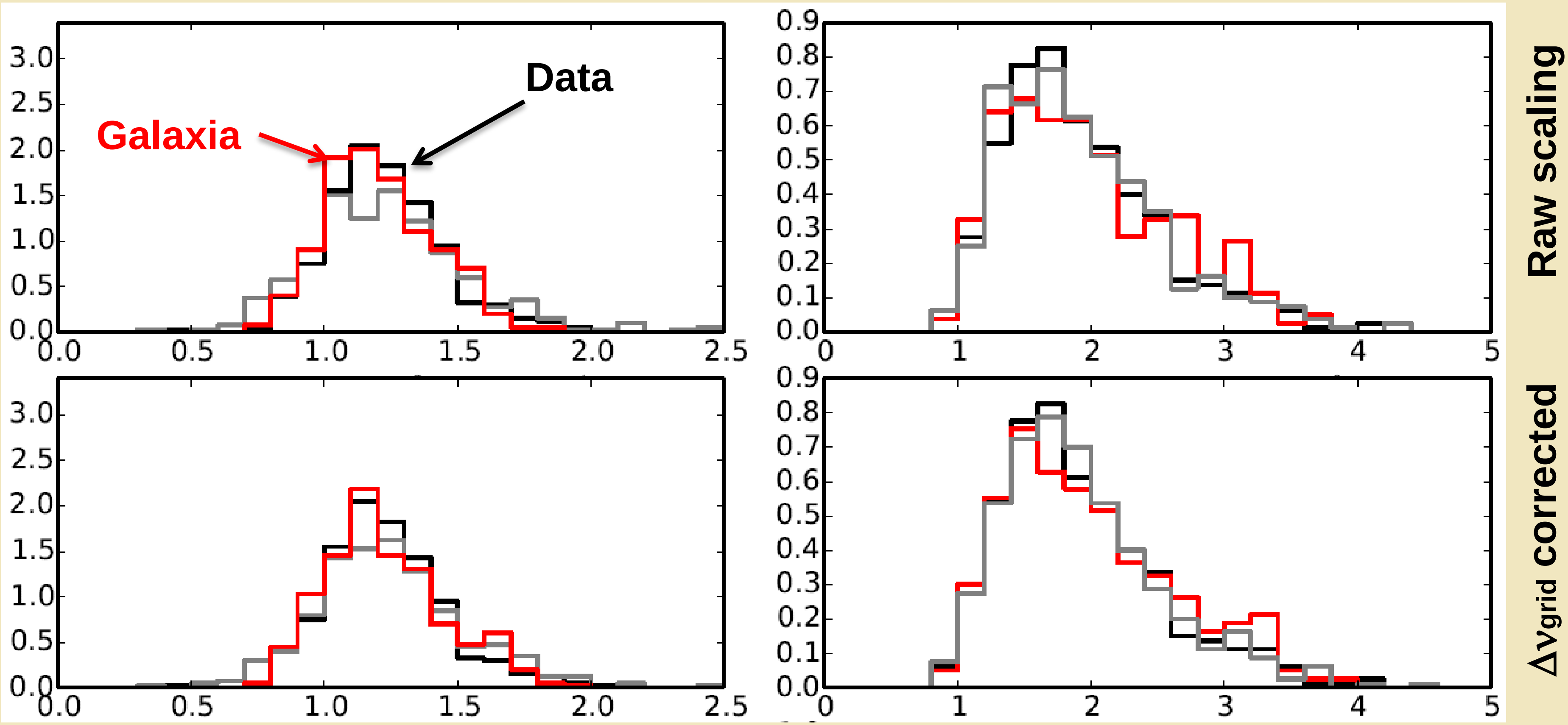






Miglio, Chiappini, Morel et al. 2013

Chaplin 2011 sample revisited

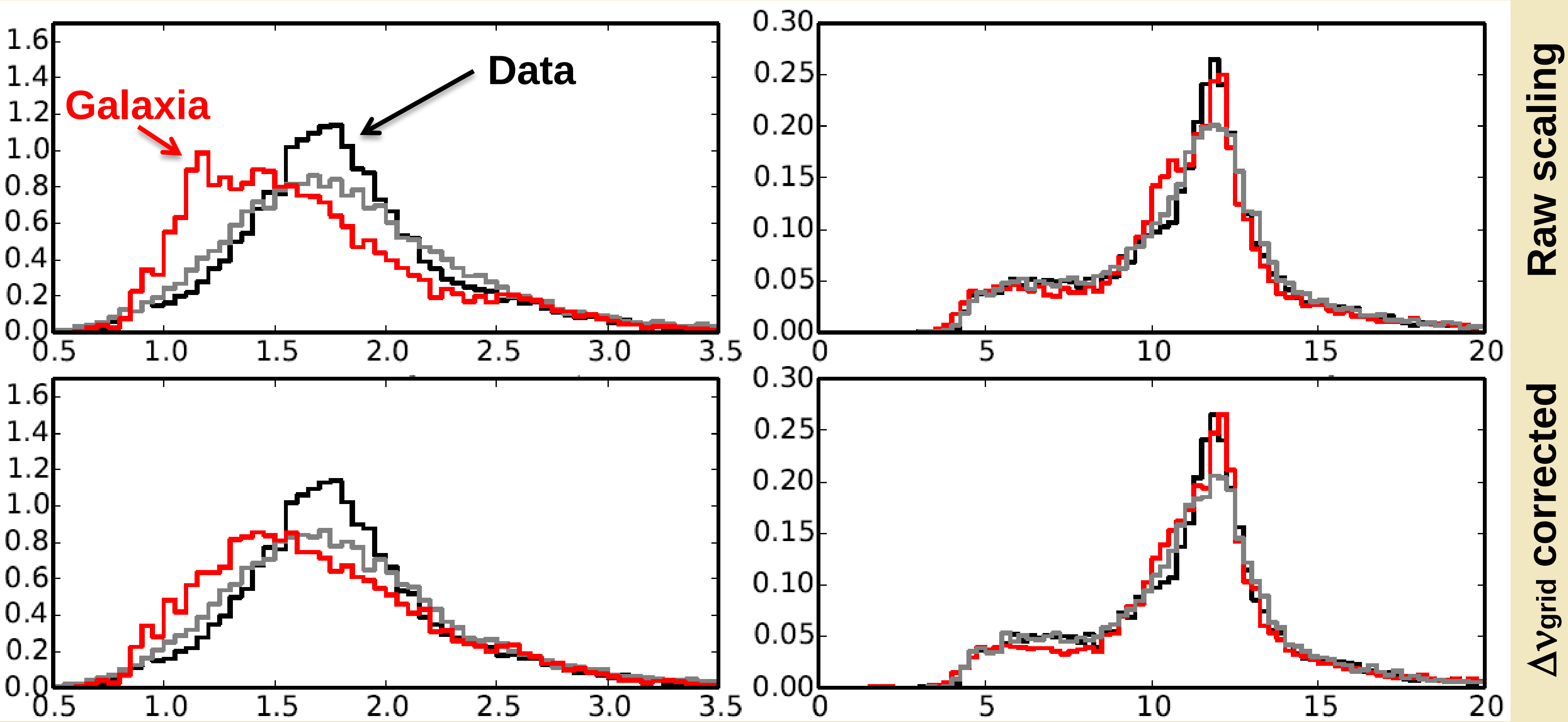


\`Mass' ($=\nu_{max}^3/\Delta\nu^4$) \`Radius' ($=\nu_{max}/\Delta\nu^2$)

Sharma, Stello et al. (in prep)

Hot out of the oven from Kepler

`Public' red giant sample

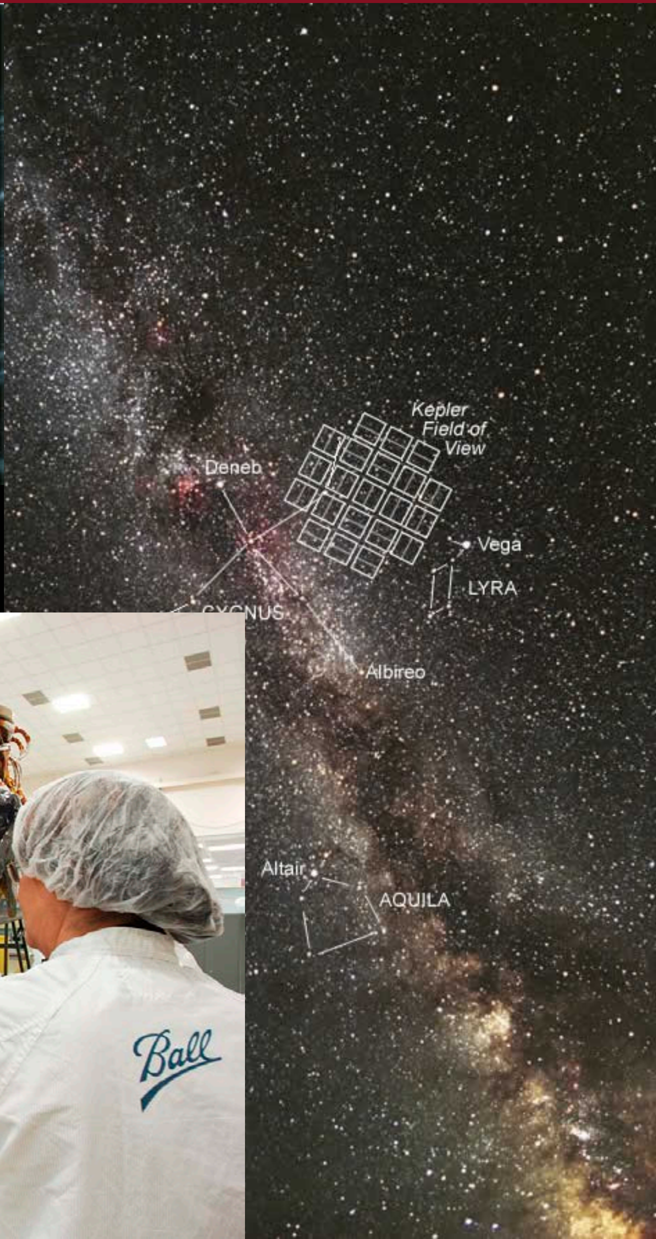


`Mass' ($=\nu_{max}^3/\Delta\nu^4$)

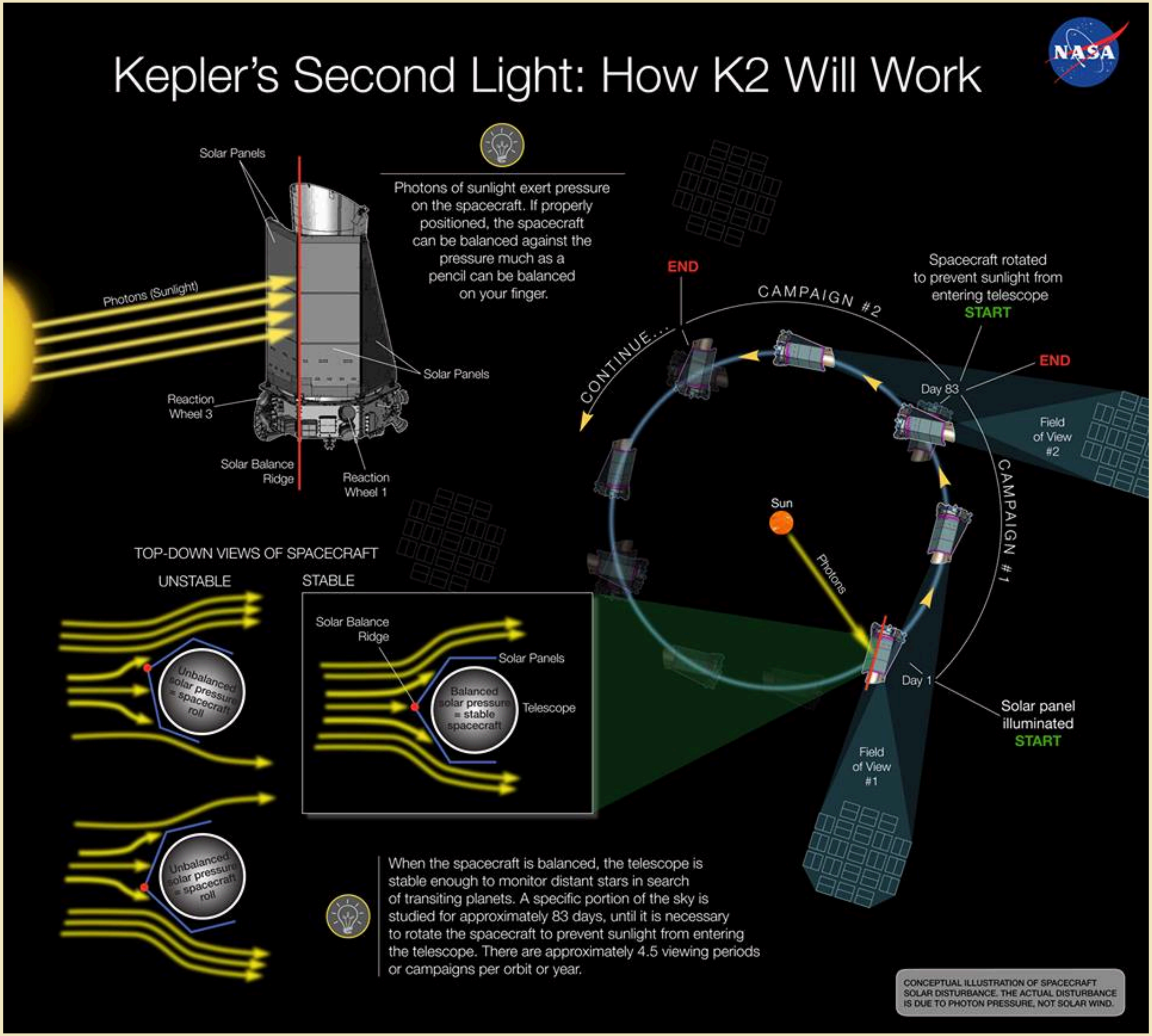
`Radius' ($=\nu_{max}/\Delta\nu^2$)

Sharma, Stello et al. (in prep)

The Kepler mission 2009-2013

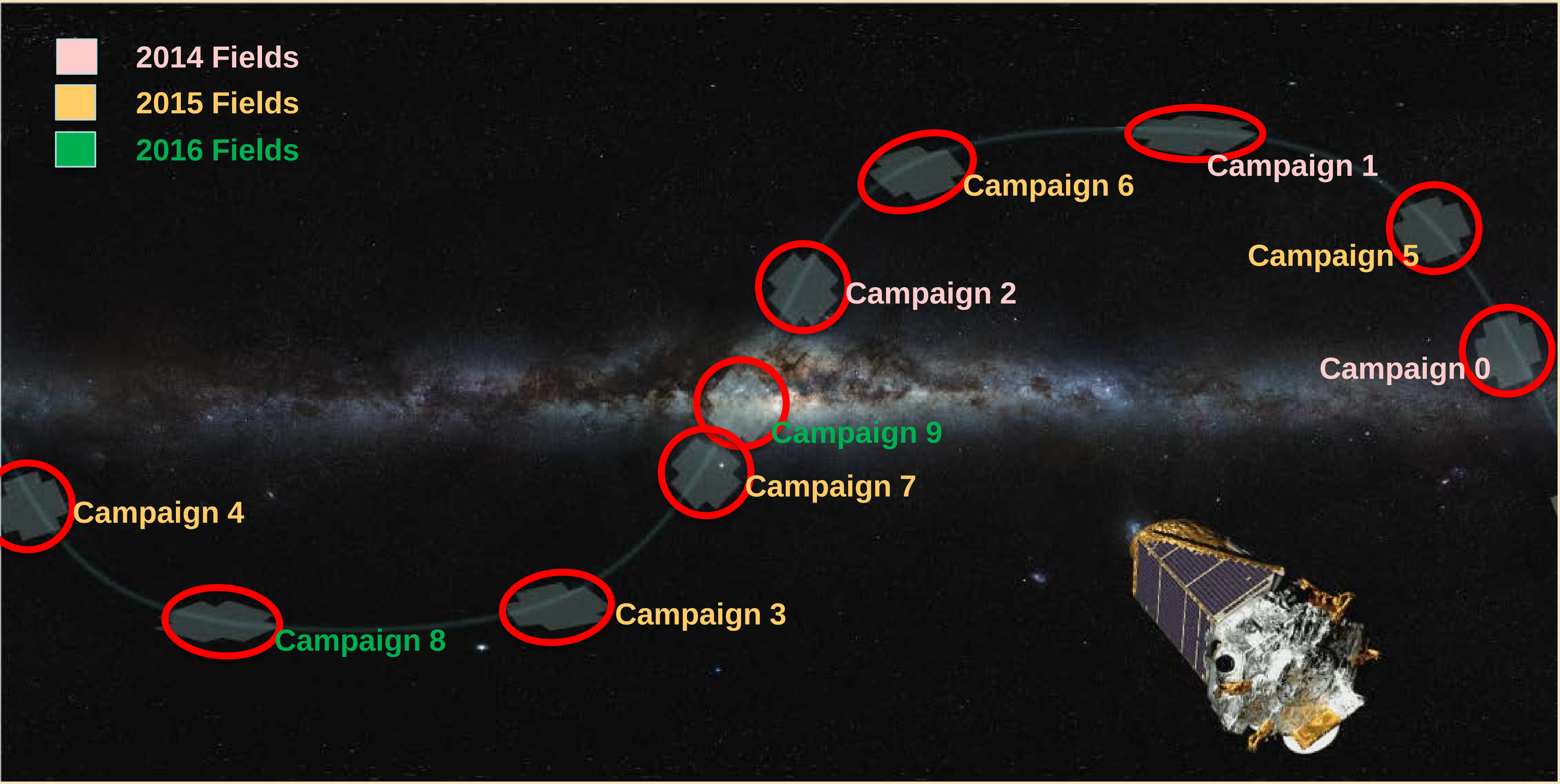


K2: The concept

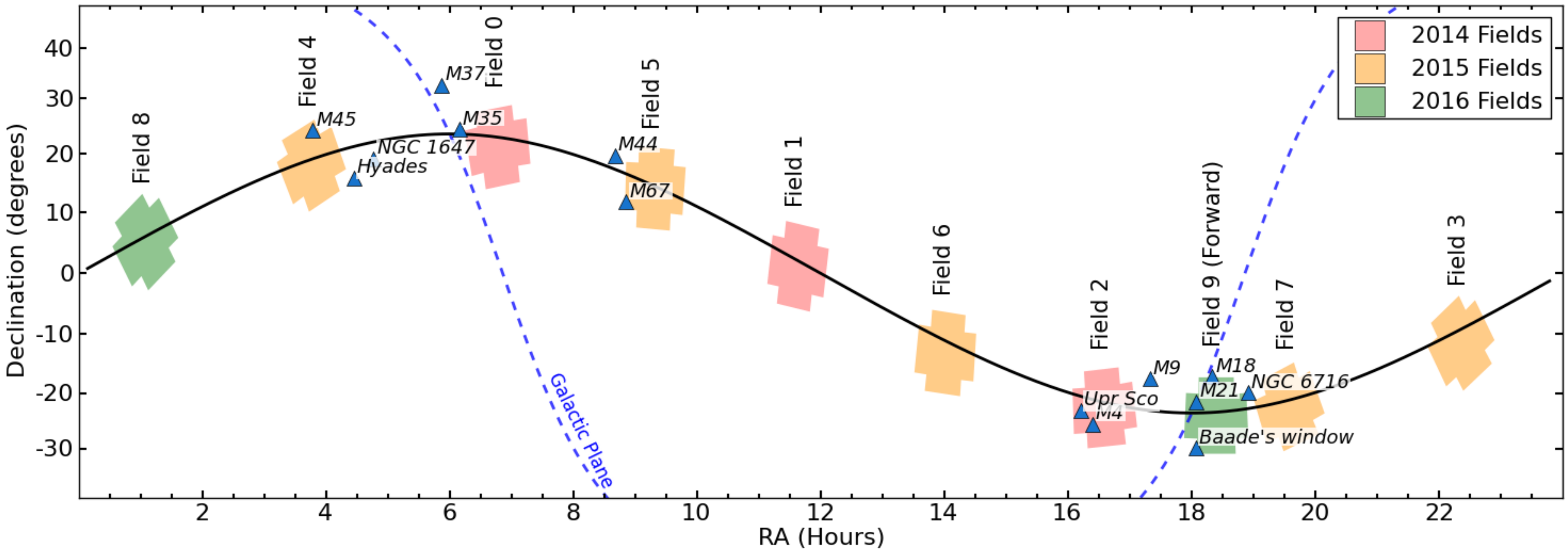


K2: Funded 2 yrs of campaigns

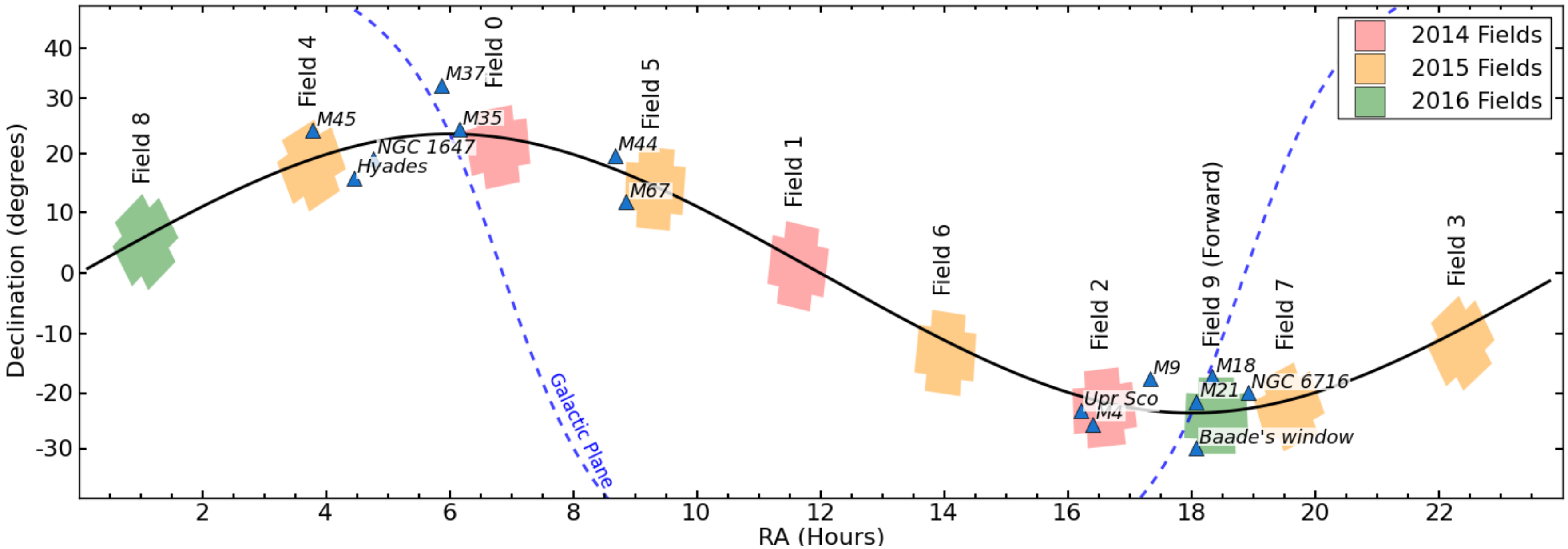
Each campaign field: 10-20K stars observed for ~80 days



"Galactic coordinates"



RA and Dec coordinates



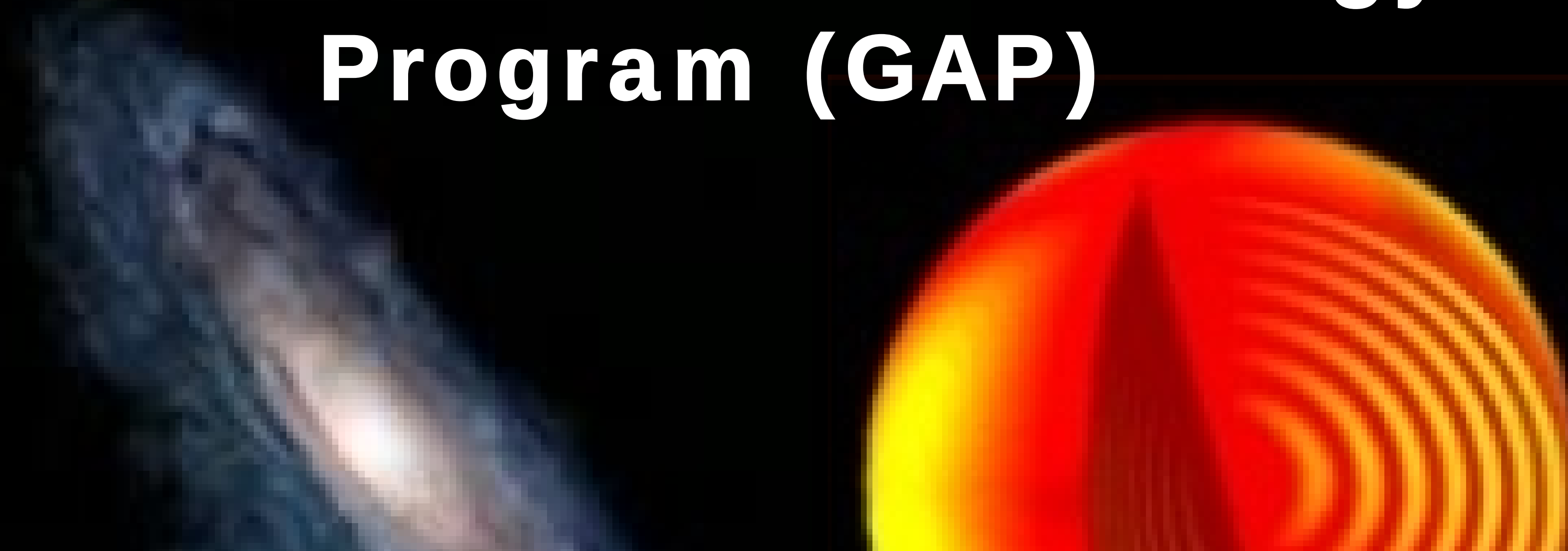
Calibrated pixels delivered	Field	Start	Stop	RA (J2000)	Dec (J2000)	Targets	Comments
Sep 2014	0	2014 Mar 08	2014 May 30	06:33:11.1	+21:35:16	✓	Near Galactic Anti-center, M35, NGC 2158
Dec 2015	1	2014 May 30	2014 Aug 21	11:35:45.5	+01:25:02	✓	North Galactic Cap
March 2015?	2	2014 Aug 23	2014 Nov 10	16:24:31.2	-22:27:00	✓	Near Galactic Center, M4, M80, M19, Upr Sco, rho Oph
	3	2014 Nov 14	2015 Feb 03	22:26:40.8	-11:06:00	✓	South Galactic Cap, Neptune
	4	2015 Feb 07	2015 Apr 24	03:56:18.2	+18:39:38		M45 (Pleiades), NGC1647, Hyades
	5	2015 Apr 26	2015 Jul 11	08:40:37.8	+16:49:47		M44 (Beehive), M67
	6	2015 Jul 13	2015 Oct 01	13:39:27.6	-11:17:43		North Galactic Cap
	7	2015 Oct 03	2015 Dec 26	19:11:18.8	-23:21:36		Near Galactic Center, NGC 6717
	9	2016 Apr 06	2016 Jun 29	18:01:25.1	-21:46:47		Galactic Center, Baades Window, M21, M18, M25, M8

FINAL K2 CAMPAIGN FIELDS

K2: Summary

- Instrument is performing well.
- Spacecraft has fuel for at least 2 years, perhaps 4+ years.
- Remaining reaction wheels are behaving.
- Temperature increases in electronics (beyond normal).
- Initial increase in reaction time for Attitude Control System (ACS) resulted in noise being motion dominated.
- Decrease in ACS reaction time starting in C3 (reduce motion noise by factor 3-4).
  - Kepler : 12mag, 6.5hr → 30ppm
  - K2 C0-2: 60ppm (C0 worst!)
  - K2 C3+ : 40ppm expected
  - noise likely to depend on star location on CCD array.

The K2 Galactic Archaeology Program (GAP)



PI: Dennis Stello, CoIs: Derek Buzasi, Ken Freeman, Savita Mathur, Andrea Miglio, Sanjib Sharma, Marc Pinsonneault, Collaborators: Friedrich Anders, Borja Anguiano, Martin Asplund, Sarbani Basu, Paul Beck, Othman Benomar, Maria Bergemann, Joss Bland-Hawthorn, Tiago Campante, Luca Casagrande, Peter De Cat, Márcio Catelan, Bill Chaplin, Cristina Chiappini, Enrico Corsaro, Orlagh Creevey, Eric Depagne, Patrick Eggenberger, Yvonne Elsworth, Jianning Fu, Rafael A. Garcia, Leo Girardi, Jennifer Johnson, Ulrike Heiter, Saskia Hekker, Paola Marigo, Eric Michel, Annie Robin, Maurizio Salaris, Victor Silva Aguirre, Marica Valentini

The K2 Galactic Archaeology Program (GAP)

The thrust: Use seismology of red giants (K2) combined with T_{eff} and [Fe/H] (ground-based) to probe the structure of the Milky Way

PI: Dennis Stello, CoIs: Derek Buzasi, Ken Freeman, Savita Mathur, Andrea Miglio, Sanjib Sharma, Marc Pinsonneault, Collaborators: Friedrich Anders, Borja Anguiano, Martin Asplund, Sarbani Basu, Paul Beck, Othman Benomar, Maria Bergemann, Joss Bland-Hawthorn, Tiago Campante, Luca Casagrande, Peter De Cat, Márcio Catelan, Bill Chaplin, Cristina Chiappini, Enrico Corsaro, Orlagh Creevey, Eric Depagne, Patrick Eggenberger, Yvonne Elsworth, Jianning Fu, Rafael A. Garcia, Leo Girardi, Jennifer Johnson, Ulrike Heiter, Saskia Hekker, Paola Marigo, Eric Michel, Annie Robin, Maurizio Salaris, Victor Silva Aguirre, Marica Valentini

Fundamental questions

The K2 Galactic Archaeology Program (GAP)

(1) Is the halo made entirely of debris of accreted material or does it include stars born in the Milky Way?
(2) How is the thick disk formed?
(3) What does the age–metallicity and velocity–metallicity relations look like at large distances from the Sun?

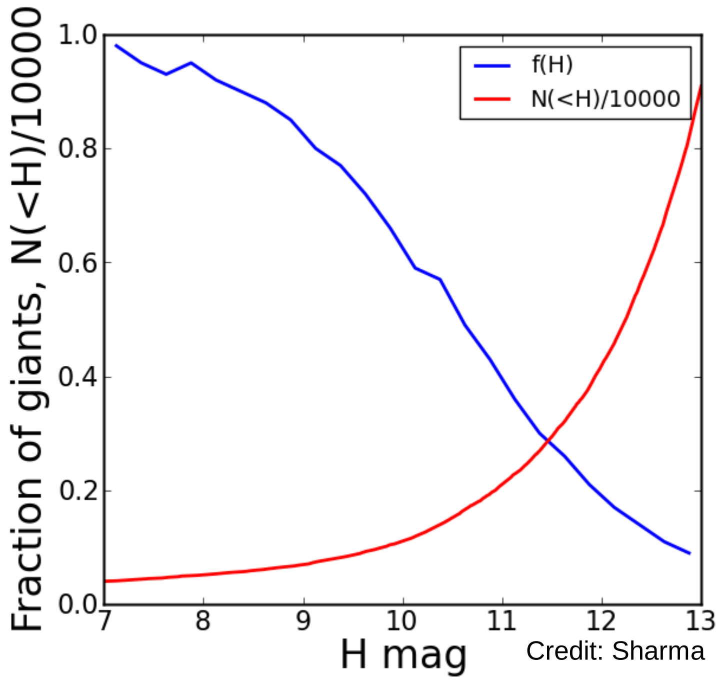
K2 GAP

- **Observational strategy:**
  - **Target 5K-10K stars (~5K red giants) at each campaign**
  - **Use simple/reproducible section criteria!**

$J–K > 0.5$, $V > 9$ sorted by V (entire field)

or

$J–K > 0.5$, $9 < V < 13.5$ random by V (few dense sub-fields)



Credit: Sharma

K2 GAP

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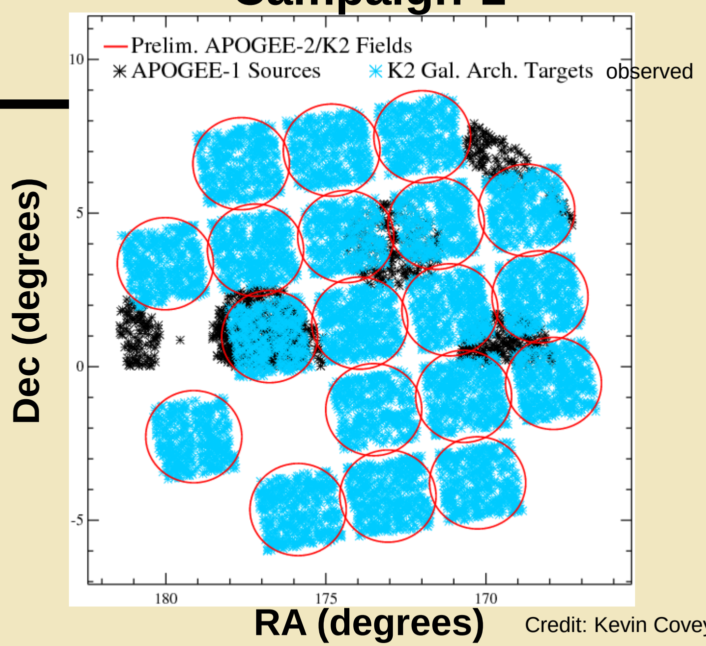
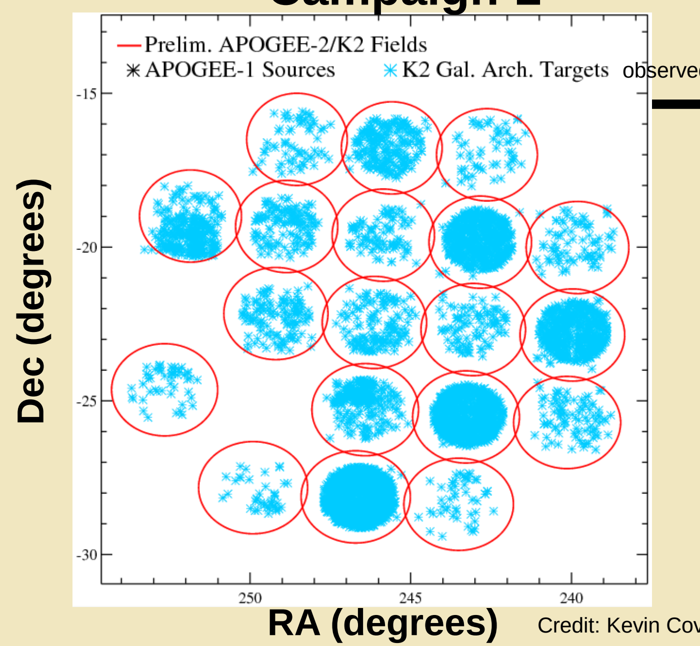
Campaign-1



Credit: Kevin Covey

Campaign-2



Credit: Kevin Covey

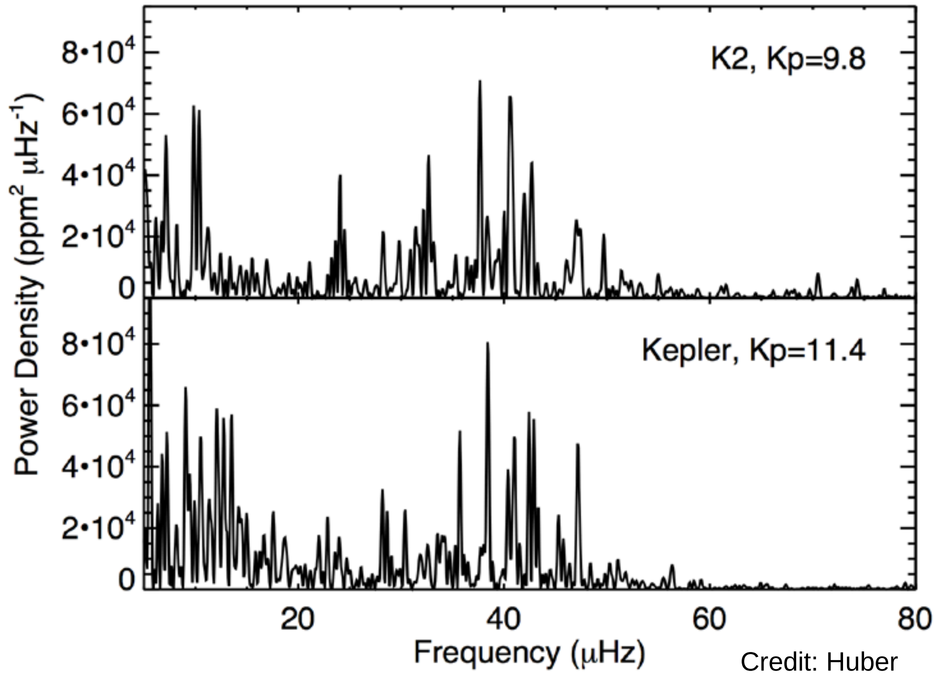
K2 GAP

- <u>**Status of observations:**</u>

Campaign	$N_{targets}$	APOGEE-1	APOGEE-2	GALAH	Gaia-ESO	LAMOST	SAGA
0	452	●	✖	✖	?	○	✖
1	8629	◕	○	○	?	○	○
2	5138	◕	◔	●	?	✖	◔
3	3904	✖	◔	●	?	✖	◔
4	6357	◕	○	●	?	○	○
5	?	◕	○	○	?	○	○
6+	?	◕	○	○	?	◔	◔
	~40%						

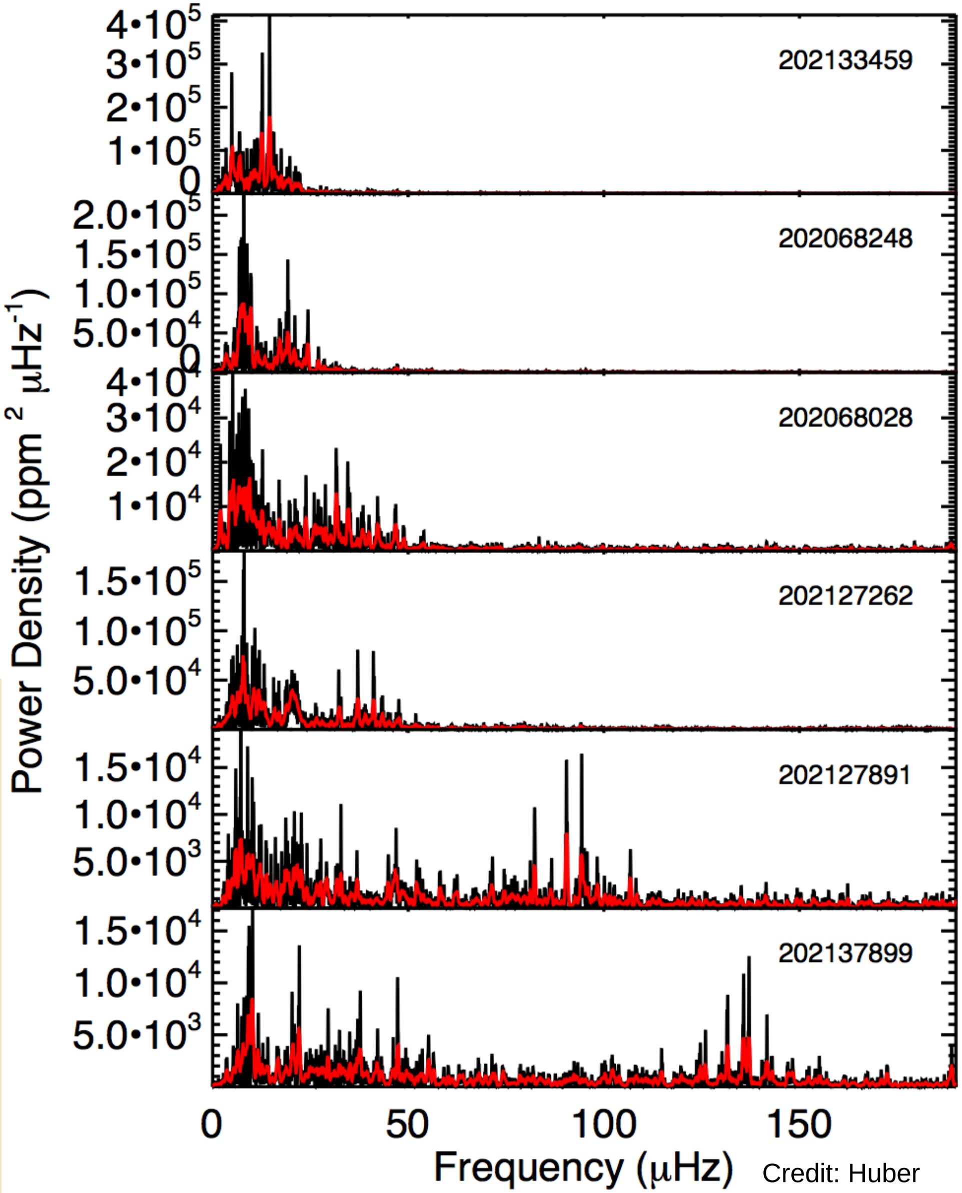
- **Don’t forget serendipitous red giants that fall within the pixel stamps of any K2 target => unbiased sample.**

K2 GAP: C0



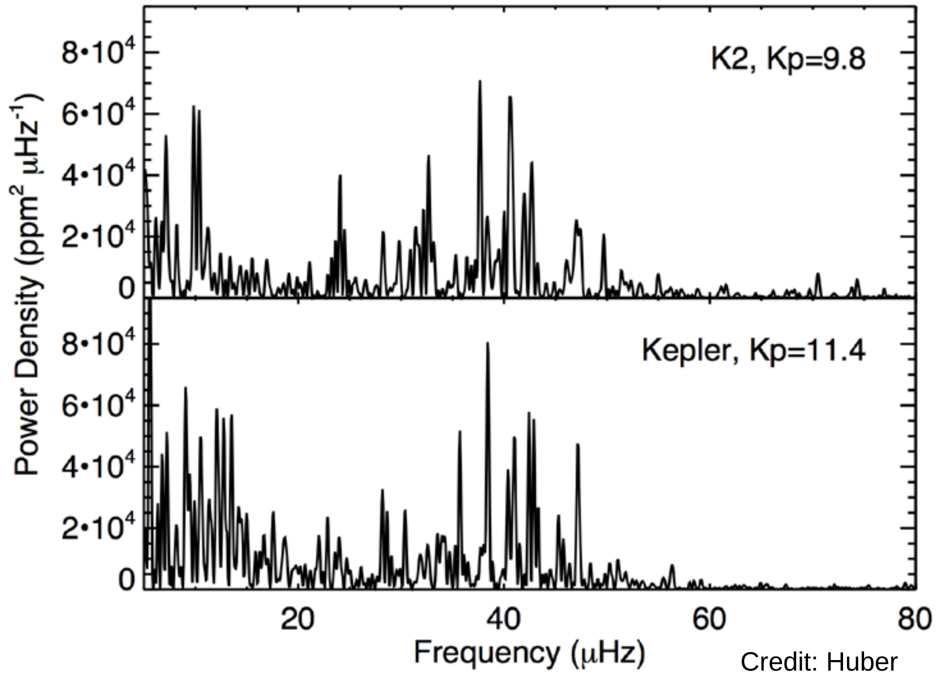
Credit: Huber

Campaign 0

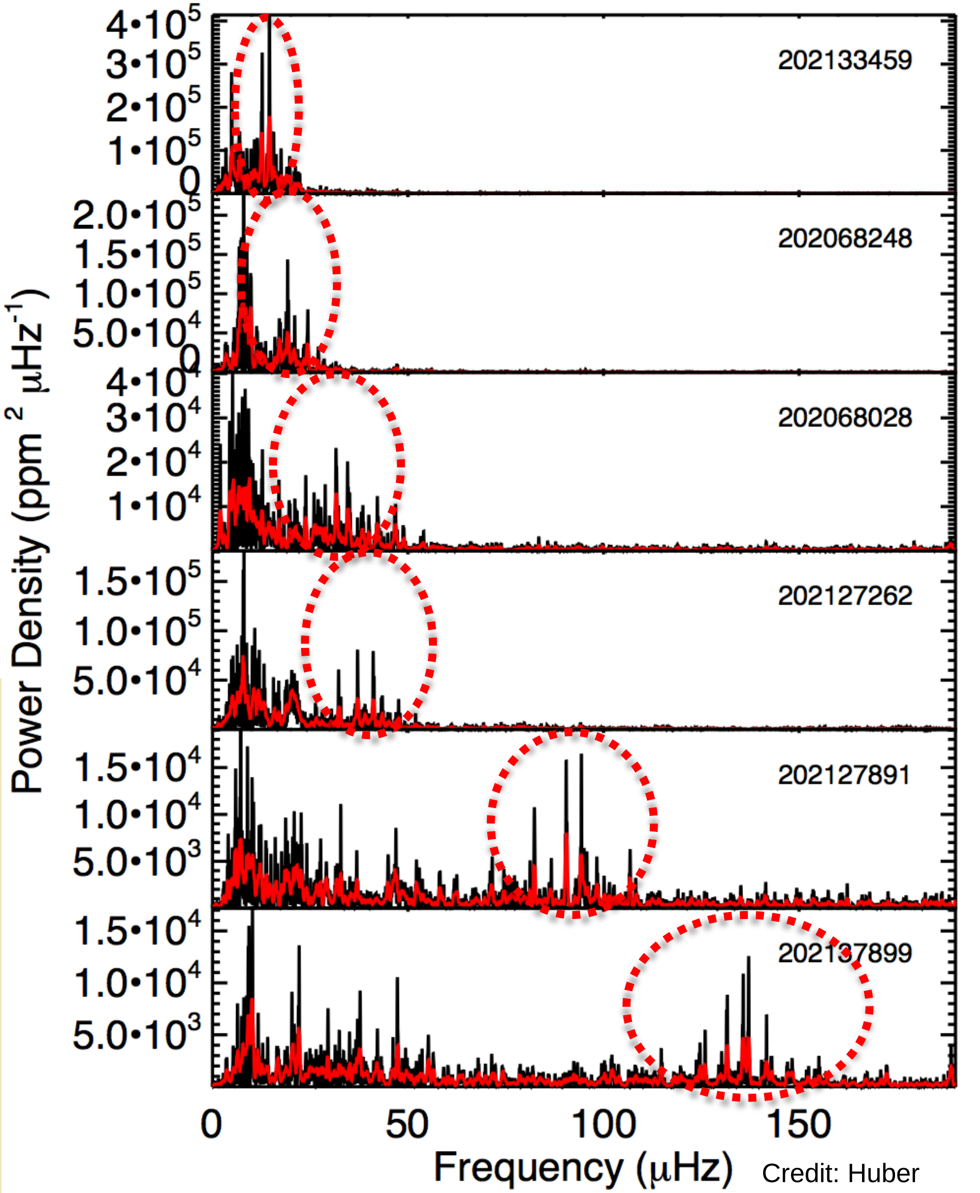


Credit: Huber

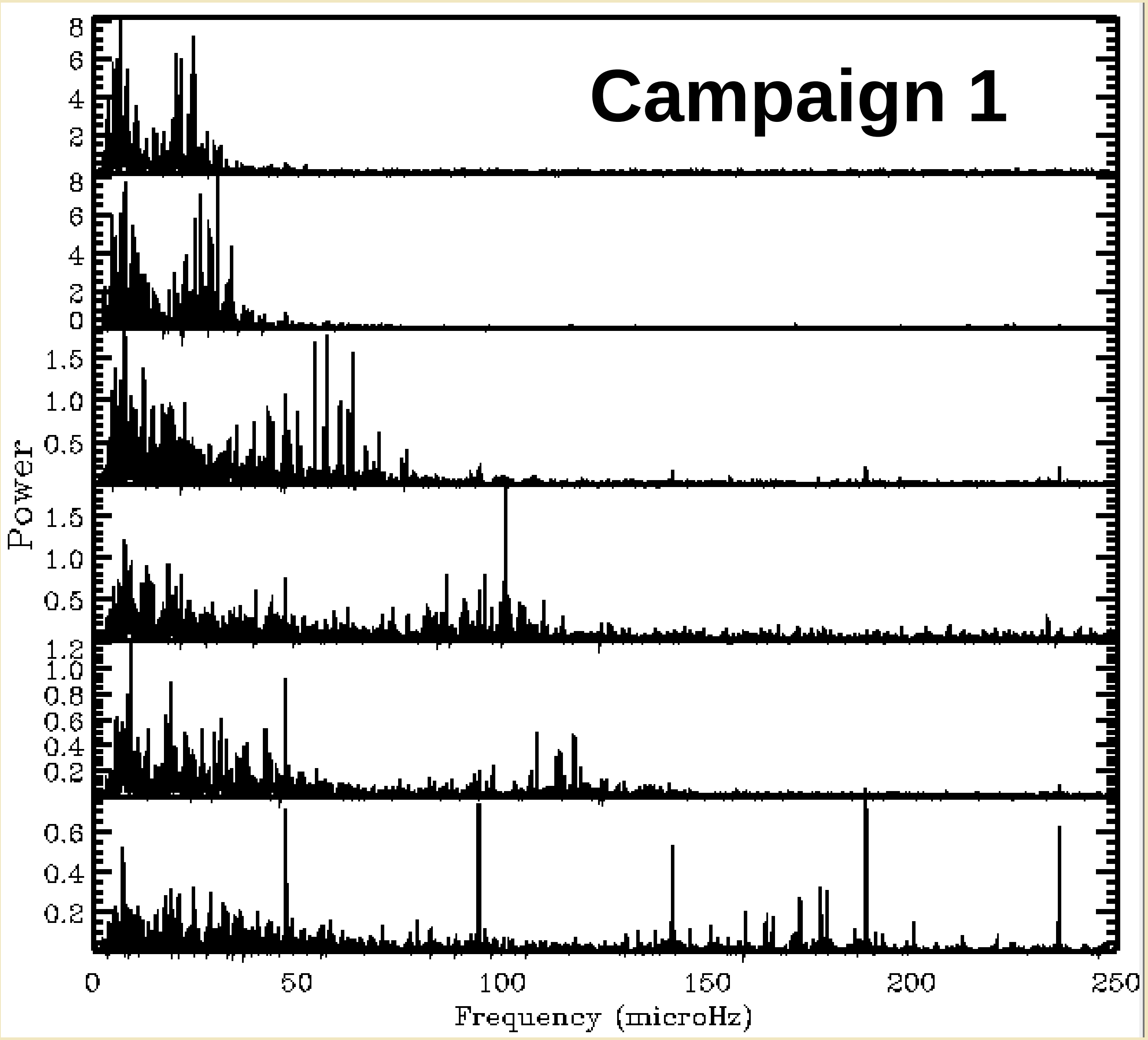
K2 GAP: C0



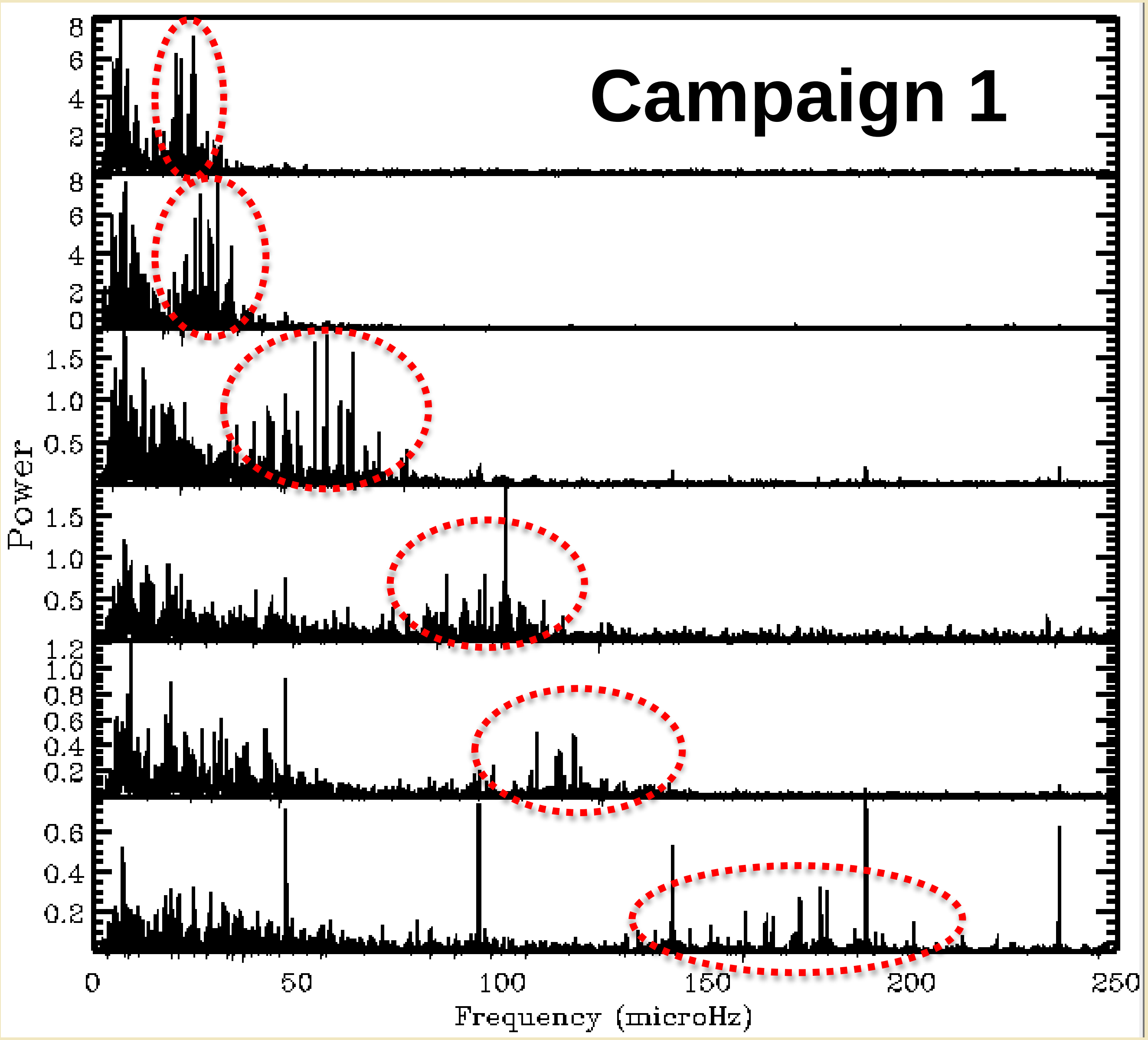
Campaign 0



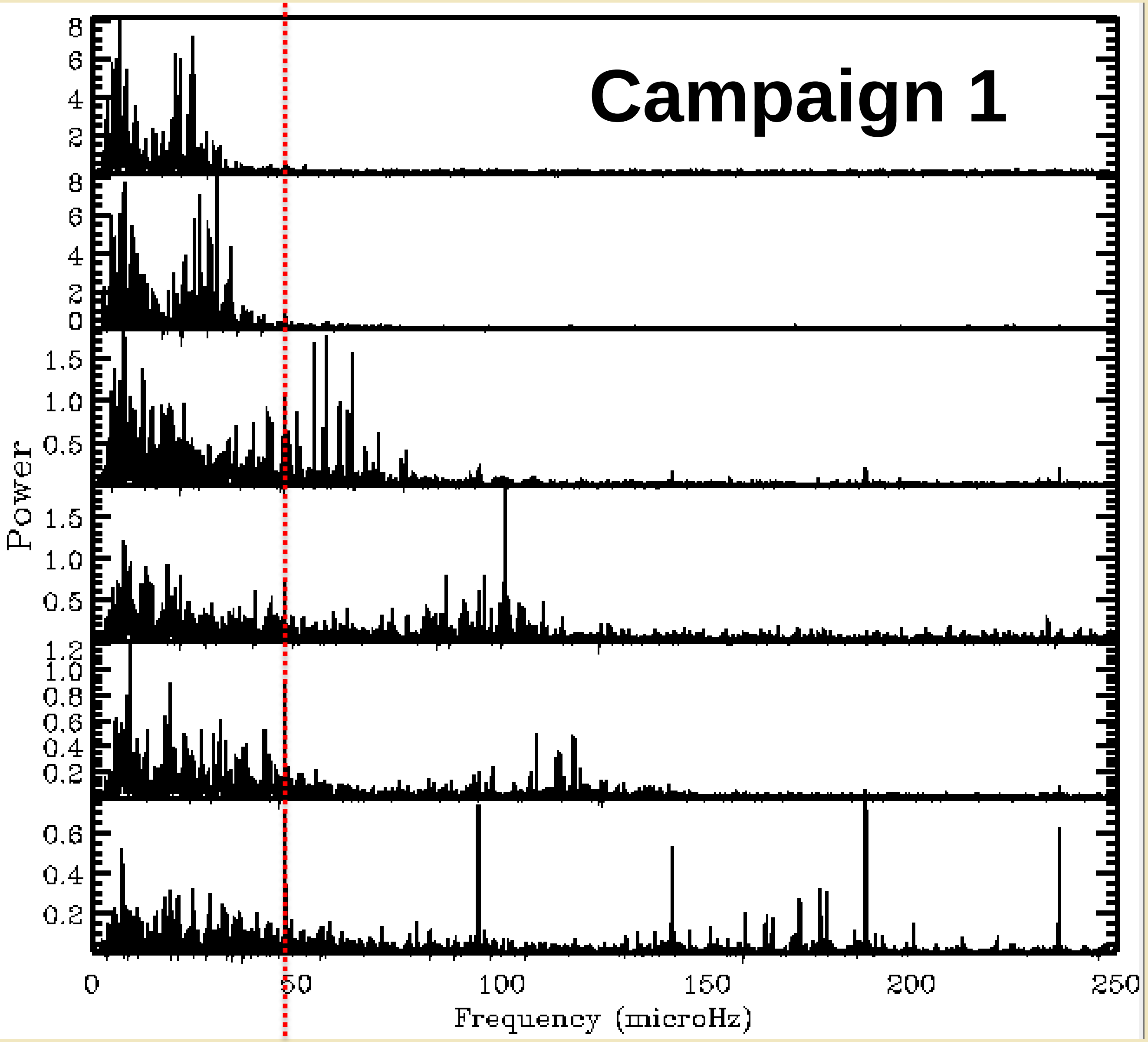
K2 GAP: C1



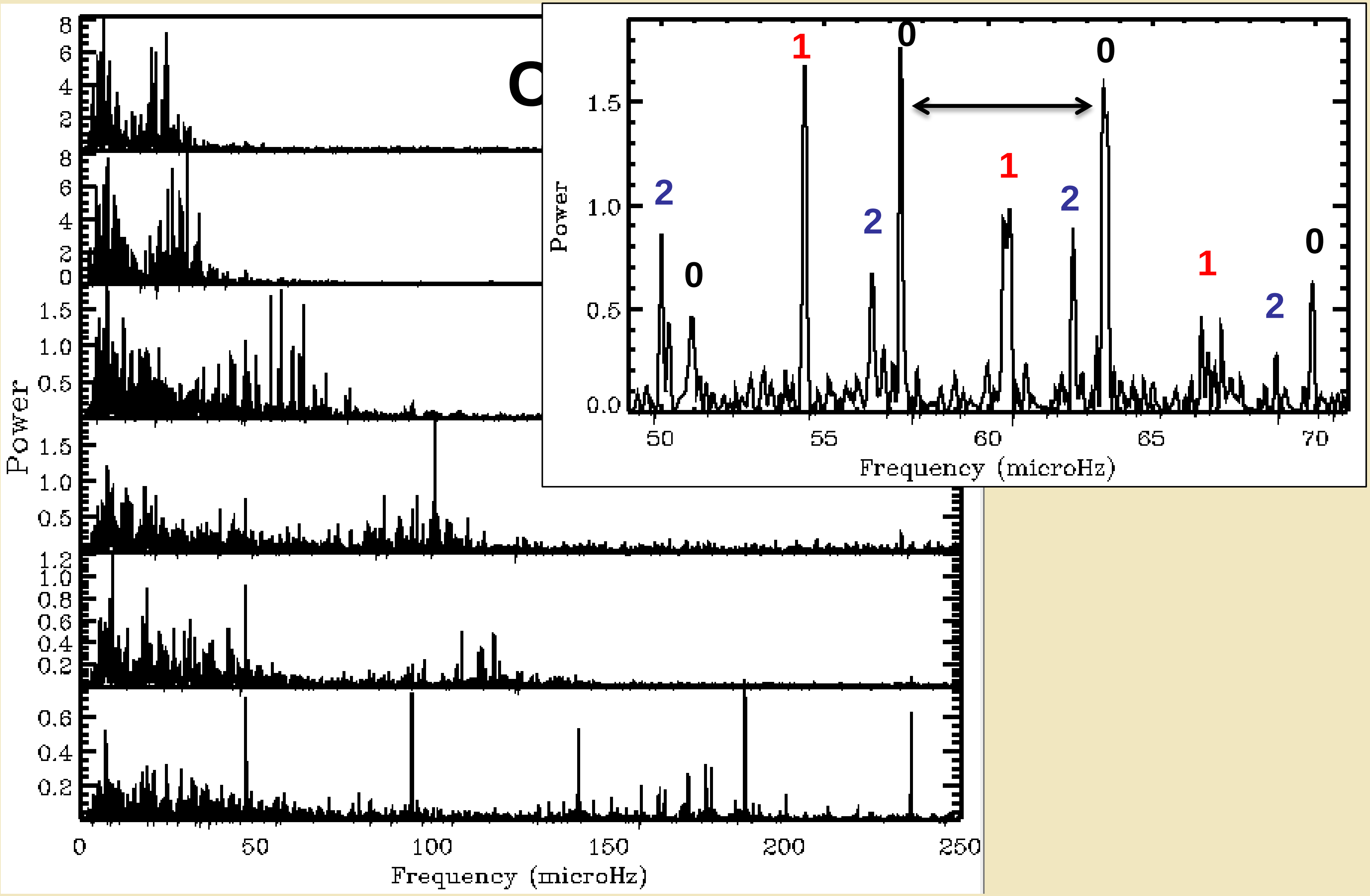
K2 GAP: C1



K2 GAP: C1



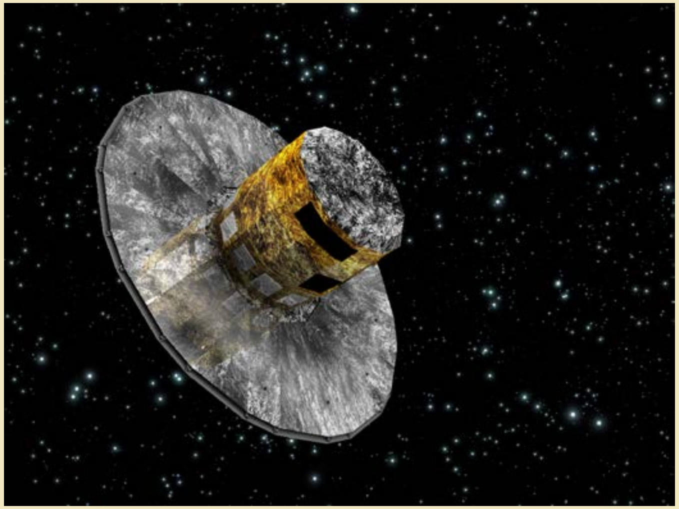
K2 GAP: C1



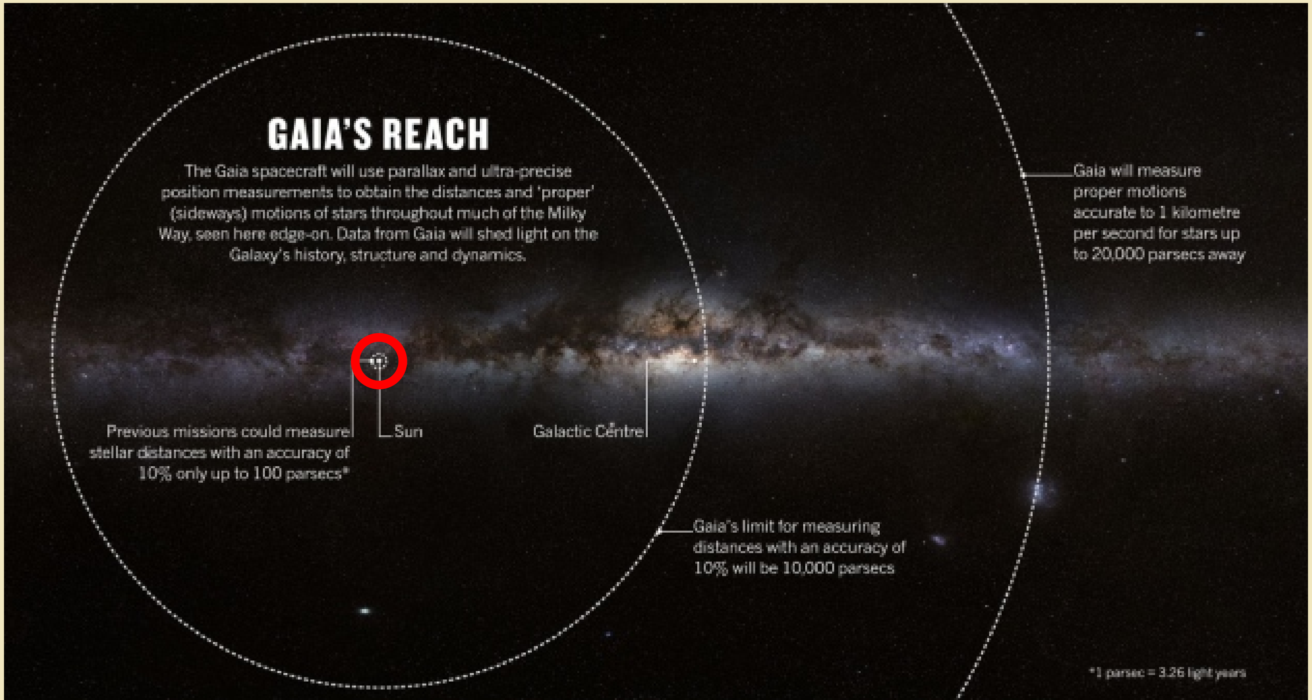
Power
Frequency (microHz)
0
50
100
150
200
250
Power
Frequency (microHz)
50
55
60
65
70
0.0
0.5
1.0
1.5
2
0
1
0
2
0
1
2
0
1
2
0

Future space missions

Gaia (ESA) launched Dec 2013



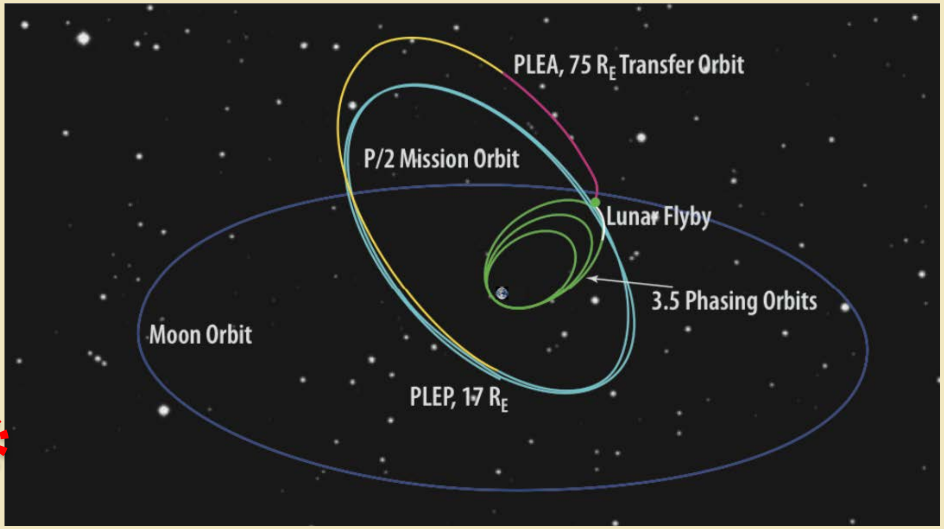
- **1 billion stars Positions (2D), distances (3D), proper motions (5D)**
- **Radial velocities (15%) 6D phase space**
- **Abundances (0.3%)**



TESS: 2017-2019+

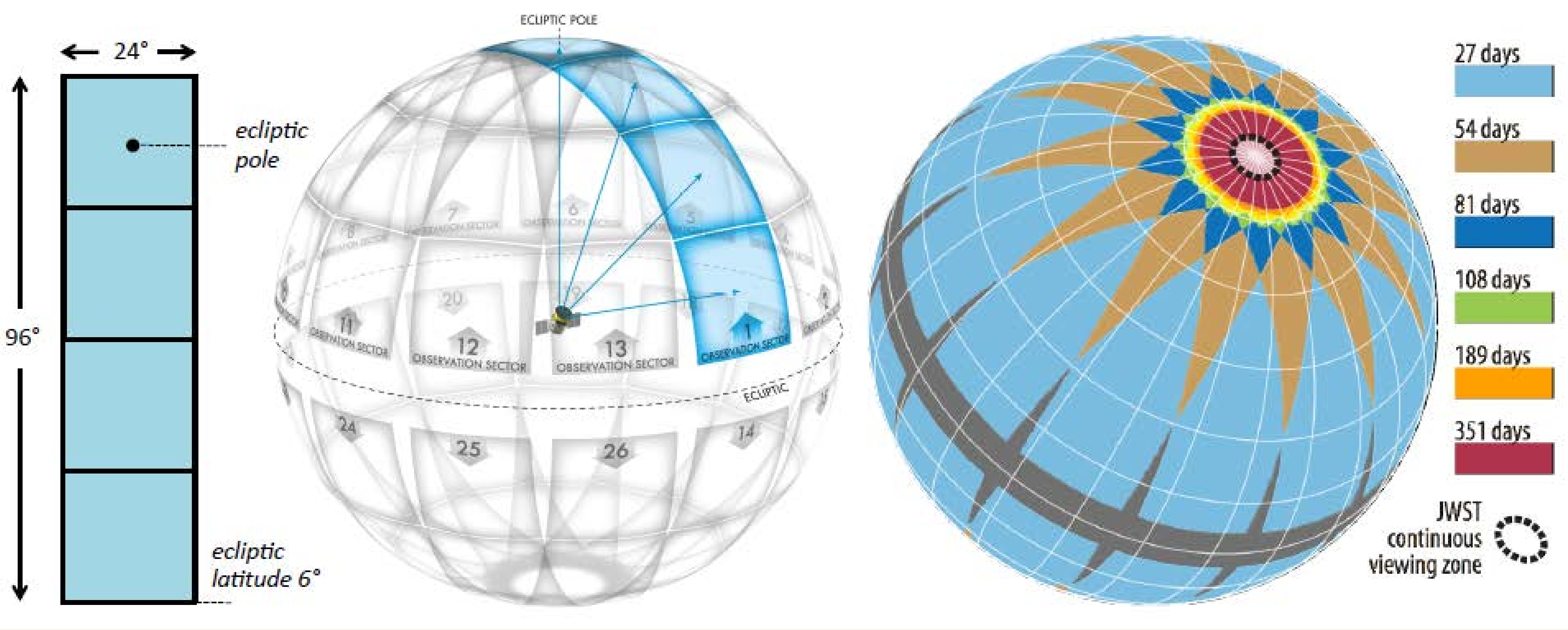
- **Primary Goal:** Discover Transiting Earths and Super-Earths Orbiting Bright, Nearby Stars
  - Rocky Planets & Water Worlds
  - Habitable planets
- Discover the “Best” ~1000 **Small** Exoplanets
  - “Best” means “Readily characterizable”
  - Measurable mass & atmospheric properties

- **Large Area Survey of Bright Stars**
  - F, G, K dwarfs: +4 to +12 magnitude
  - M dwarfs known within ~60 parsecs
  - “All sky” observations in 2 years:
    - > 200,000 target stars at <2 min cadence
    - > 20,000,000 stars in full frames at 30 min cadence

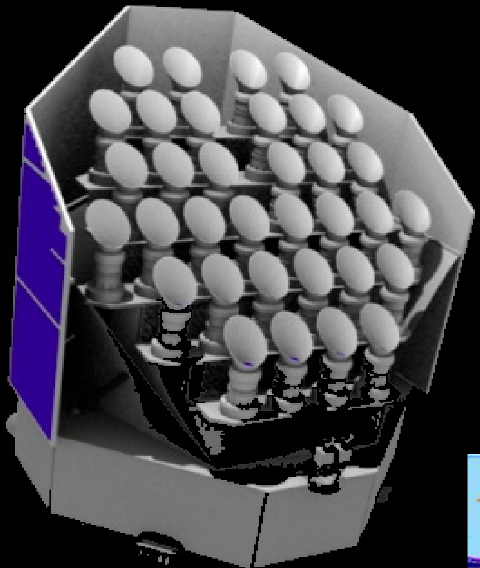


TESS: 2017-2019+

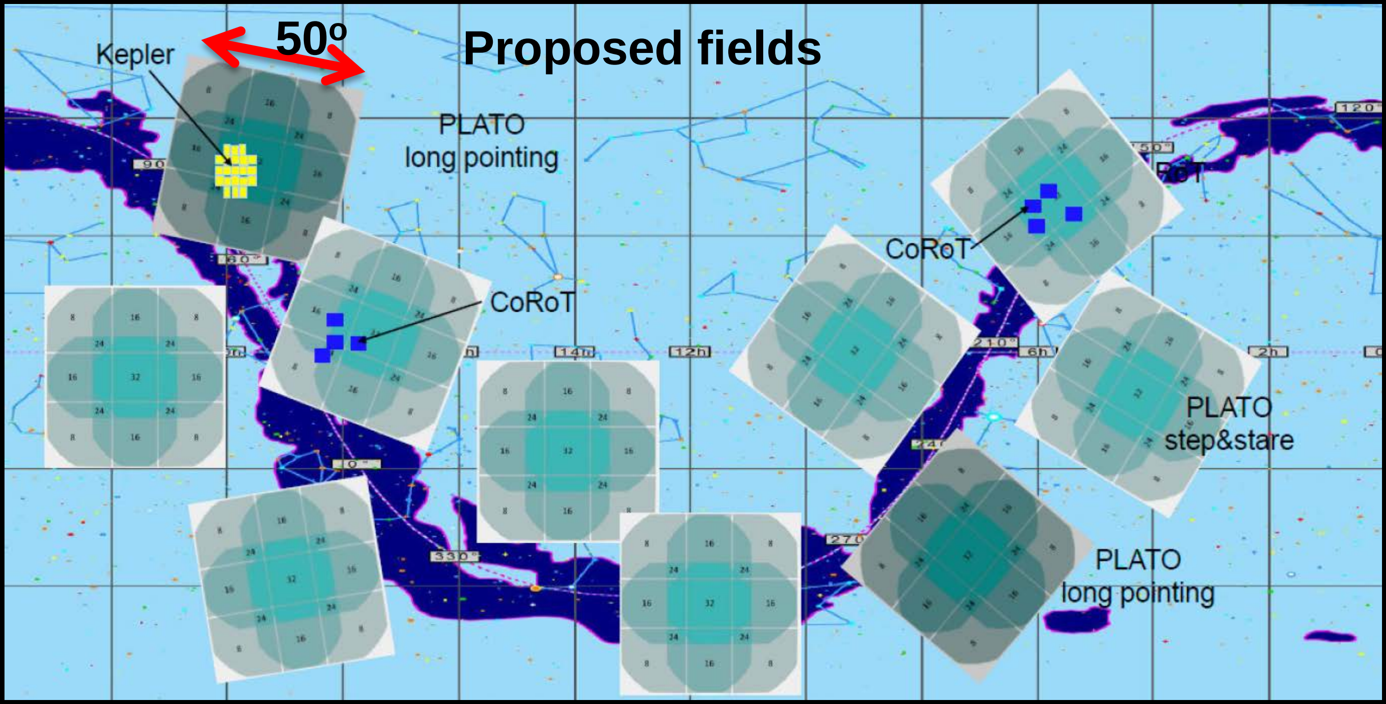
All-sky observing strategy



PLATO: 2022-2028+



- Large Area Survey
  - *4-16 magnitude*
  - *50% of entire sky observed in 6 years:*
    - *~ 100,000 target stars at 2.5 sec cadence*
    - *> 1,000,000 stars at 25 sec cadence*

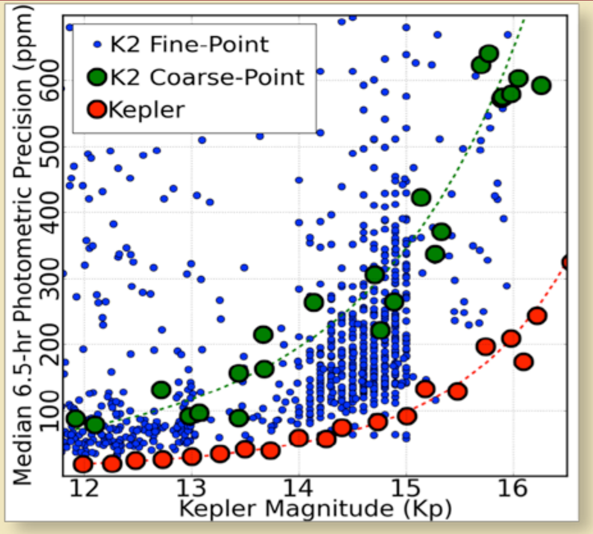


Discussion topics

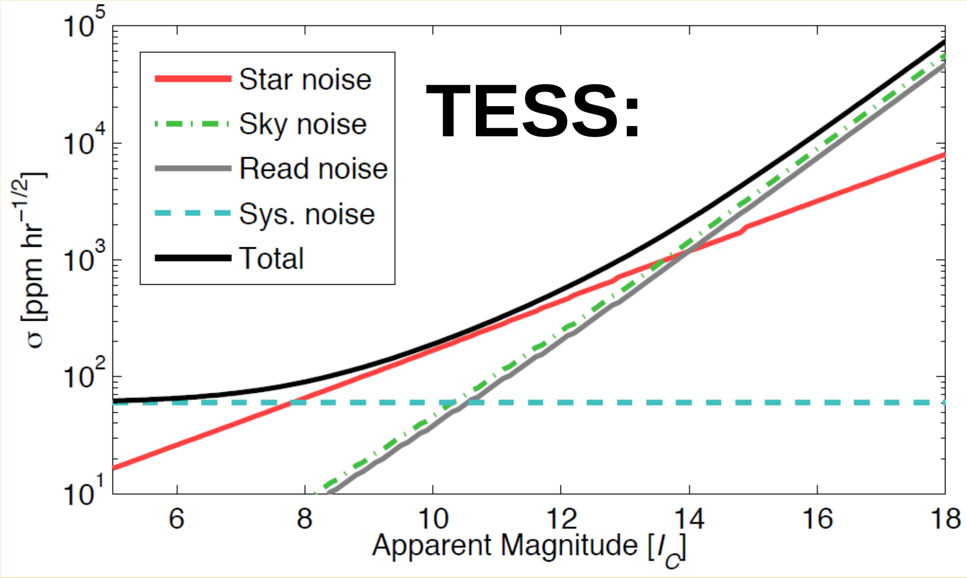
- Ground-based follow-up for K2
- K2 light curves optimised for red giant seismology
- Serendipitous red giants in pixel stamps
- The K2 GAP beyond campaign 9
- We should start thinking about TESS (Target selection, Data access, Data products, Ground-based follow-up).

Future of space photometry

K2:



TESS:



PLATO: